IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF DELAWARE

INTERMEC IP CORP., a Delaware corporation, Plaintiff, v. ALIEN TECHNOLOGY CORP., a Delaware corporation, Defendant.	)	C.A. No. **DEMAND FOR JURY TRIAL**

COMPLAINT FOR PATENT INFRINGEMENT

Plaintiff, Intermec IP Corp. ("Intermec"), for its Complaint against Defendant Alien Technology Corp. ("Alien") hereby alleges:

JURISDICTION AND VENUE

1. This action arises under the patent laws of the United States, 35 U.S.C. § 101 et seq. This Court has jurisdiction under 28 U.S.C. § 1338(a).

2. Venue is proper in this judicial district pursuant to 28 U.S.C. §§ 1391(c) and 1400(b).

THE PARTIES

3. Plaintiff Intermec is incorporated under the laws of the State of Delaware, and has its principal place of business at 6001 36th Ave. West, Everett, WA 98203.

4. On information and belief, Defendant Alien is incorporated under the laws of the State of Delaware, and has its principal place of business at 18220 Butterfield Blvd., Morgan Hill, California 95037.

ASSERTED PATENTS

5. On June 18, 1996, the United States Patent and Trademark Office ("PTO") issued U.S. Patent No. 5,528,222 (the "'222 Patent") to Paul Moskowitz, Michael J. Brady and Paul W. Coteus for their invention entitled "Radio Frequency Circuit and Memory in Thin Flexible Package." Intermec owns all right and title to the '222 Patent. A copy of the '222 Patent is attached hereto as Exhibit A.

6. On July 7, 1998, the United States Patent and Trademark Office ("PTO") issued U.S. Patent No. 5,777,561 (the "'561 Patent") to Trieu Can Chieu, Thomas Anthony Cofino, Harley Kent Heinrich, Paul Jorge Sousa, and Li-Cheng Richard Zai for their invention entitled "Method of Grouping RF Transponders." Intermec owns all right and title to the '561 Patent. A copy of the '561 Patent is attached hereto as Exhibit B.

7. On October 27, 1998, the PTO issued U.S. Patent No. 5,828,318 (the "'318 Patent") to Christian Lenz Cesar for his invention entitled "System and Method for Selecting a Subset of Autonomous and Independent Slave Entities." Intermec owns all right and title to the '318 Patent. A copy of the '318 Patent is attached hereto as Exhibit C.

8. On December 15, 1998, the PTO issued U.S. Patent No. 5,850,181 (the "'181 Patent") to Harley Kent Heinrich, Rene Dominic Martinez, Paul Jorge Sousa, and Li-Cheng Richard Zai for their invention entitled "Method of Transporting Radio Frequency Power to Energize Radio Frequency Identification Transponders." Intermec owns all right and title to the '181 Patent. A copy of the '181 Patent is attached hereto as Exhibit D.

9. On June 15, 1999, the PTO issued U.S. Patent No. 5,912,632 (the "'632 Patent") to David E. Dieska, Daniel Joseph Friedman, Kenneth Alan Goldman and Harley Kent Heinrich for their invention entitled "Single Chip RF Tag Oscillator Circuit Synchronized By

Base Station Modulation Frequency." Intermec owns all right and title to the '632 Patent. A copy of the '632 Patent is attached hereto as Exhibit E.

10. On November 30, 1999, the PTO issued U.S. Patent No. 5,995,019 (the "'019 Patent") to Trieu Can Chieu, Thomas Anthony Cofino, Harley Kent Heinrich, Paul Jorge Sousa and Li-Cheng Richard Zai for their invention entitled "Method for Communicating with RF Transponders." Intermec owns all right and title to the '019 Patent. A copy of the '019 Patent is attached hereto as Exhibit F.

11. On September 11, 2001, the PTO issued U.S. Patent No. 6,286,762 (the "'762 Patent") to Andrew E. Reynolds, Christopher A. Wiklof, and Daniel B. Bodnar for their invention entitled "Method and Apparatus to Perform a Predefined Search on Data Carriers, Such as RFID Tags." Intermec owns all right and title to the '762 Patent. A copy of the '762 Patent is attached hereto as Exhibit G.

12. On June 4, 2002, the PTO issued U.S. Patent No. 6,400,274 (the "'274 Patent") to Dah-Weih Duan, Daniel J. Friedman, Harley Kent Heinrich, Ian Bardwell-Jones, and Joe Ruggiero for their invention entitled "High-Performance Mobile Power Antennas." Intermec owns all right and title to the '274 Patent. A copy of the '274 Patent is attached hereto as Exhibit H.

13. On November 2, 2004, the PTO issued U.S. Patent No. 6,812,841 (the "'841 Patent") to Harley Kent Heinrich, Vigay Pillai, and David E. Dieska for their invention entitled "Passive RFID Tag That Retains State After Temporary Loss of Power." Intermec owns all right and title to the '841 Patent. A copy of the '841 Patent is attached hereto as Exhibit I.

14. On November 2, 2004, the PTO issued U.S. Patent No. 6,812,852 (the "'852 Patent") to Christian Lenz Cesar for his invention entitled "System and Method for

Selecting a Subset of Autonomous and Independent Slave Entities." Intermec owns all right and title to the '852 Patent. A copy of the '852 Patent is attached hereto as Exhibit J. (The '222, '561, '318, '181, '632, '019, '762, '274, '841, and '852 Patents are collectively referred to as "patents-in-suit.")

15. The patents-in-suit relate to Radio Frequency Identification ("RFID") technology, which has many applications. The object of any RFID system is to carry data in suitable transponders, generally known as tags, and to retrieve the data, by machine-readable means, at a suitable time and place to satisfy particular application needs. Data within a tag may provide identification for an item in manufacture, goods in transit, a location and/or identity of a vehicle, an animal or individual. By including additional data, it is possible to provide applications with item specific information or instructions immediately available on reading the tag, for example, the color of paint for a car body entering a paint spray area on the production line, the set-up instructions for a flexible manufacturing cell or the manifest to accompany a shipment of goods.

16. An RFID system requires, in addition to tags, a means of reading or interrogating the tags and some means of communicating the data to a host computer or information management system. In an RFID system, an interrogating device emits a radio signal to activate the tag and read data from it and, in some instances, write data to it.

ACCUSED PRODUCTS

17. Alien makes, uses, sells and/or offers for sale RFID products, including RFID readers and tags, that infringe the patents-in-suit.

18. These products include, but are not limited to, Alien's RFID Reader ALR-9800, and its RFID Tags ALL-9440 "Gen2 Squiggle™" and ALL-9460 "Omni-Squiggle™". (These products are collectively referred to as "Accused Products.")

FIRST CLAIM FOR RELIEF
(INFRINGEMENT OF THE '222 PATENT)

19. Intermec incorporates paragraphs 1 through 18 by reference as though fully set forth herein.

20. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '222 Patent.

21. Alien's infringement of the '222 Patent has caused and will continue to cause Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '222 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

22. Upon information and belief, Alien's infringement of the '222 patent has been willful and deliberate.

SECOND CLAIM FOR RELIEF
(INFRINGEMENT OF THE '561 PATENT)

23. Intermec incorporates paragraphs 1 through 22 by reference as though fully set forth herein.

24. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '561 Patent.

25. Alien's infringement of the '561 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of the infringement of the '561 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

26. Upon information and belief, Alien's infringement of the '561 patent has been willful and deliberate.

THIRD CLAIM FOR RELIEF
(INFRINGEMENT OF THE '318 PATENT)

27. Plaintiff incorporates paragraphs 1 through 26 by reference as though fully set forth herein.

28. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '318 Patent.

29. Alien's infringement of the '318 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '318 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is

entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

30. Upon information and belief, Alien's infringement of the '318 patent has been willful and deliberate.

FOURTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '181 PATENT)

31. Intermec incorporates paragraphs 1 through 30 by reference as though fully set forth herein.

32. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '181 Patent.

33. Alien's infringement of the '181 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '181 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

34. Upon information and belief, Alien's infringement of the '181 patent has been willful and deliberate.

FIFTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '632 PATENT)

35. Intermec incorporates paragraphs 1 through 34 by reference as though fully set forth herein.

36. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '632 Patent.

37. Alien's infringement of the '632 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '632 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

38. Upon information and belief, Alien's infringement of the '632 patent has been willful and deliberate.

SIXTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '019 PATENT)

39. Intermec incorporates paragraphs 1 through 38 by reference as though fully set forth herein.

40. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '019 Patent.

41. Alien's infringement of the '019 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '019

Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

42. Upon information and belief, Alien's infringement of the '019 patent has been willful and deliberate.

SEVENTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '762 PATENT)

43. Intermec incorporates paragraphs 1 through 42 by reference as though fully set forth herein.

44. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '762 Patent.

45. Alien's infringement of the '762 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of the infringement of the '762 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

46. Upon information and belief, Alien's induced infringement of the '762 patent has been willful and deliberate.

EIGHTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '274 PATENT)

47. Intermec incorporates paragraphs 1 through 46 by reference as though fully set forth herein.

48. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '274 Patent.

49. Alien's infringement of the '274 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '274 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

50. Upon information and belief, Alien's infringement of the '274 patent has been willful and deliberate.

NINTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '841 PATENT)

51. Intermec incorporates paragraphs 1 through 50 by reference as though fully set forth herein.

52. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '841 Patent.

53. Alien's infringement of the '841 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '841 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

54. Upon information and belief, Alien's infringement of the '841 patent has been willful and deliberate.

TENTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '852 PATENT)

55. Intermec incorporates paragraphs 1 through 54 by reference as though fully set forth herein.

56. By virtue of its manufacture, use, sale, offer for sale and/or encouragement of others to use its RFID products, including the Accused Products, Alien has been and still is infringing, inducing the infringement of and/or contributing to the infringement of the '852 Patent.

57. Alien's infringement of the '852 Patent has caused, and will continue to cause, Intermec substantial and irreparable injury for which Intermec is entitled to receive adequate compensation, or injunctive relief. As a result of Alien's infringement of the '852 Patent, and Intermec's compliance with the requirements of 35 U.S.C. § 287(a), Intermec is entitled to damages adequate to compensate it for the infringement, but in no event less than a reasonable royalty.

58. Upon information and belief, Alien's infringement of the '852 patent has been willful and deliberate.

DEMAND FOR RELIEF

WHEREFORE, Intermec prays that this Court:

A. Grant injunctive relief prohibiting Defendant Alien, its officers, agents, servants, employees and attorneys, and upon those persons in active concert or participation with Defendant, from further infringement of the patents-in-suit;

B. Award Intermec its damages adequate to compensate it for Defendant's infringement, together with interest as fixed by the Court;

C. Award Intermec treble damages for Defendant's willful infringement.

D. Declare this case exceptional pursuant to 35 U.S.C. § 285 and award Intermec its costs and reasonable attorneys' fees; and

E. Grant Intermec such other and further relief as the Court deems just and proper.

DEMAND FOR JURY TRIAL

Pursuant to Fed. R. Civ. P. 38, Intermec demands trial by jury of all issues triable of right by a jury.

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(312) 360-6000

June 29, 2006

EXHIBIT A

US005528222A

United States Patent [19]

Moskowitz et al.

[11] **Patent Number: 5,528,222**

[45] **Date of Patent: Jun. 18, 1996**

[54] **RADIO FREQUENCY CIRCUIT AND MEMORY IN THIN FLEXIBLE PACKAGE**

[75] Inventors: **Paul A. Moskowitz**, Yorktown Heights; **Michael J. Brady**, Brewster; **Paul W. Coteus**, Yorktown Heights, all of N.Y.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **303,977**

[22] Filed: **Sep. 9, 1994**

[51] **Int. Cl.**[6] **H04Q 1/02**

[52] **U.S. Cl.** **340/572**; 29/825; 29/829; 29/836; 340/825.3; 340/825.34; 340/825.54

[58] **Field of Search** 340/572, 825.34, 340/825.3, 825.54; 29/836, 829, 825

[56] **References Cited**

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9411846	5/1994	WIPO .

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Patent Abstracts of Japan, vol. 13, No. 560 (M–906) 13 Dec. 1989 & JP, A, 01 234 296 (NEC Corp.) 19 Sep. 1989.

International Standard 7810, "Identification cards–Physical characteristics" First Edition–1985–12–15.

R. R. Tumalla et al, "Microelectronics Packaging Handbook", 1989, pp. 68, 76, 1154.

Primary Examiner—Glen Swann
Attorney, Agent, or Firm—Louis J. Percello

[57] **ABSTRACT**

A novel thin and flexible radio frequency (RF) tag has a semiconductor circuit with logic, memory, and a radio frequency circuits, connected to an antenna with all interconnections placed on a single plane of wiring without crossovers. The elements of the package (substrate, antenna, and laminated covers) are flexible. The elements of the package are all thin. The tag is thin and flexible, enabling a unique range of applications including: RF ID tagging of credit cards, passports, admission tickets, and postage stamps.

29 Claims, 10 Drawing Sheets

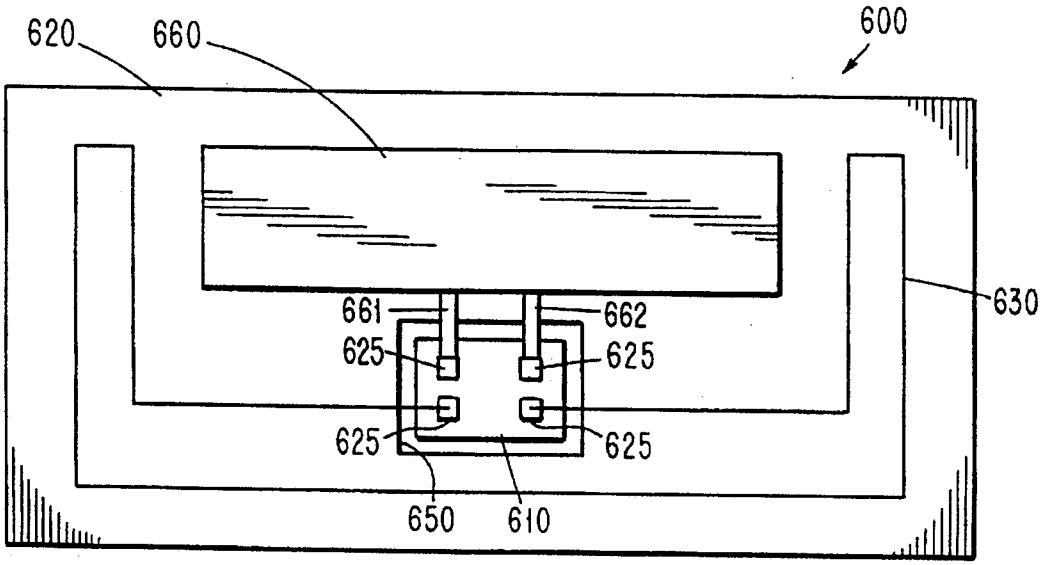

FIG. 1A
PRIOR ART

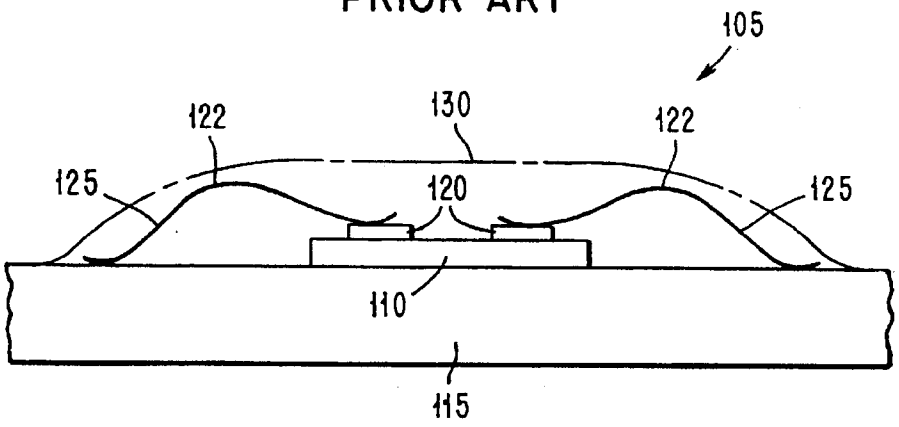

FIG. 1B
PRIOR ART

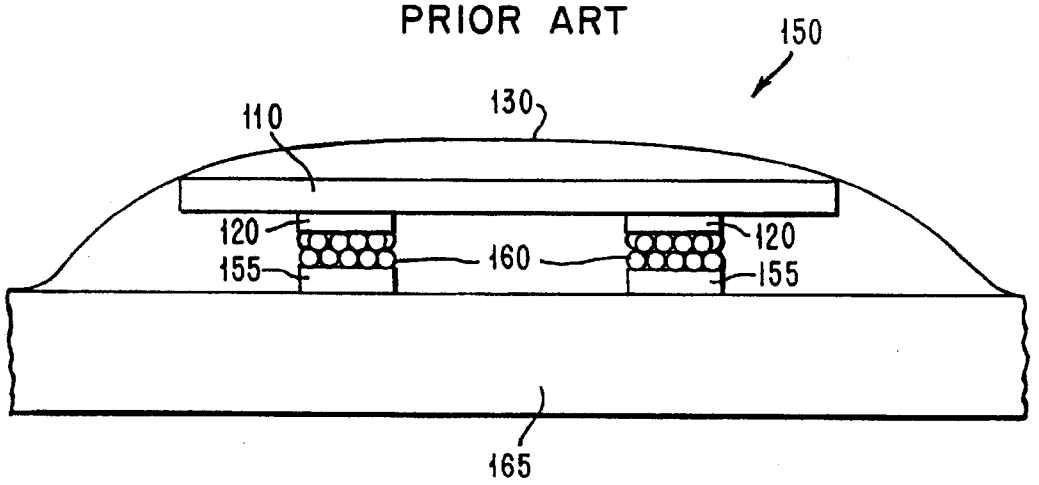

FIG. 2

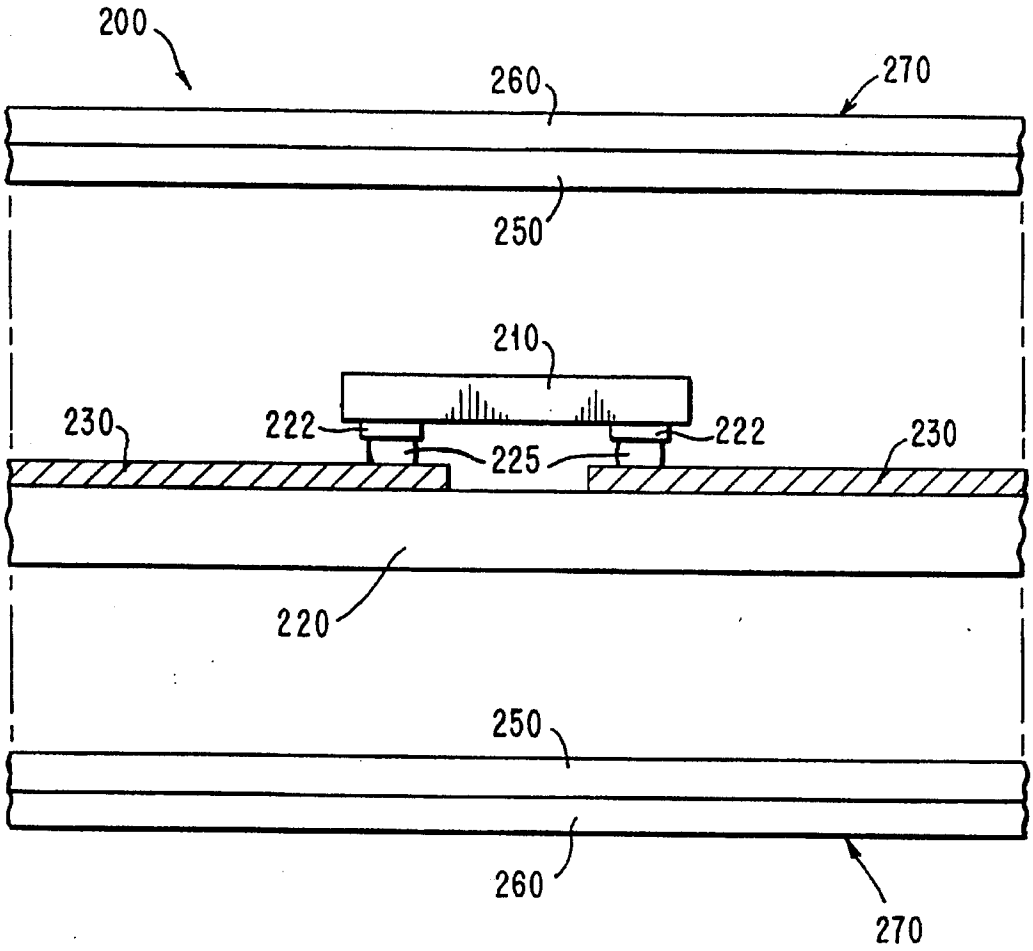

FIG. 3

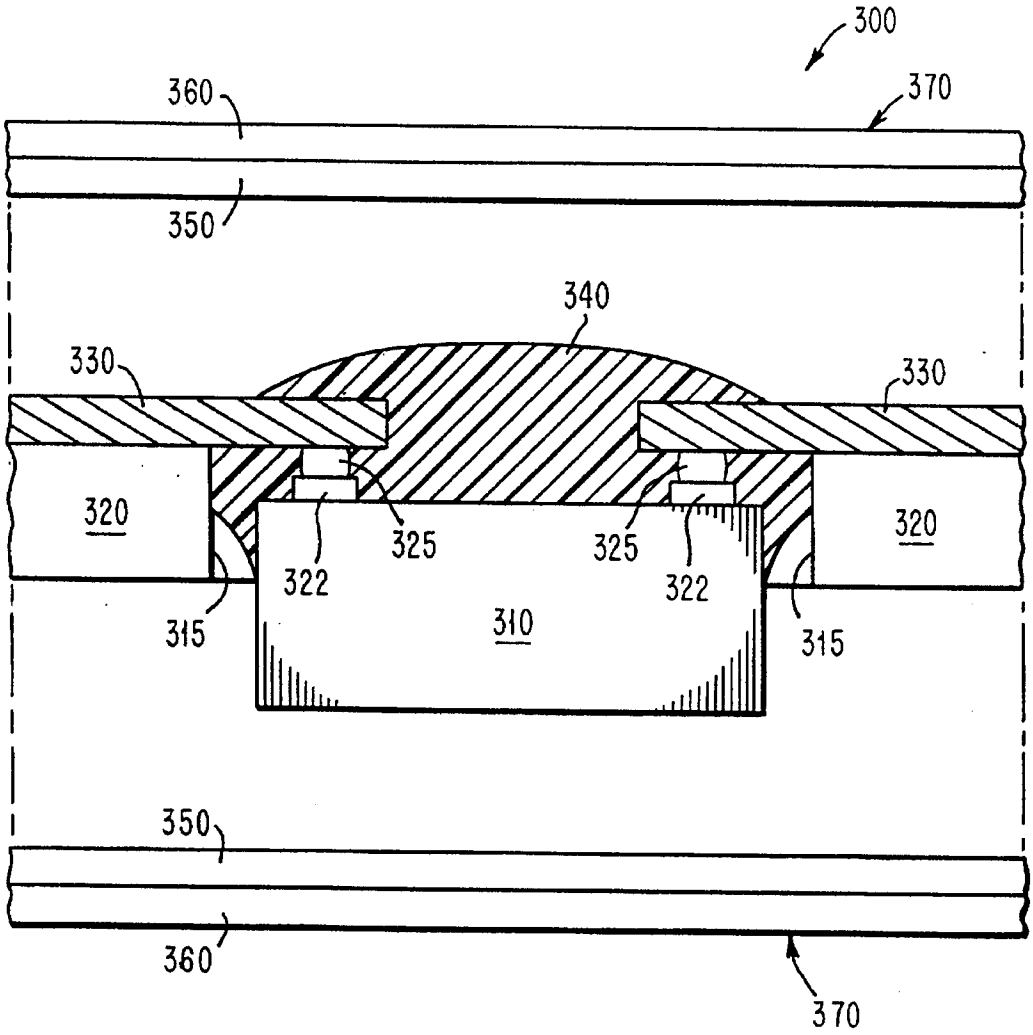
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FIG. 4

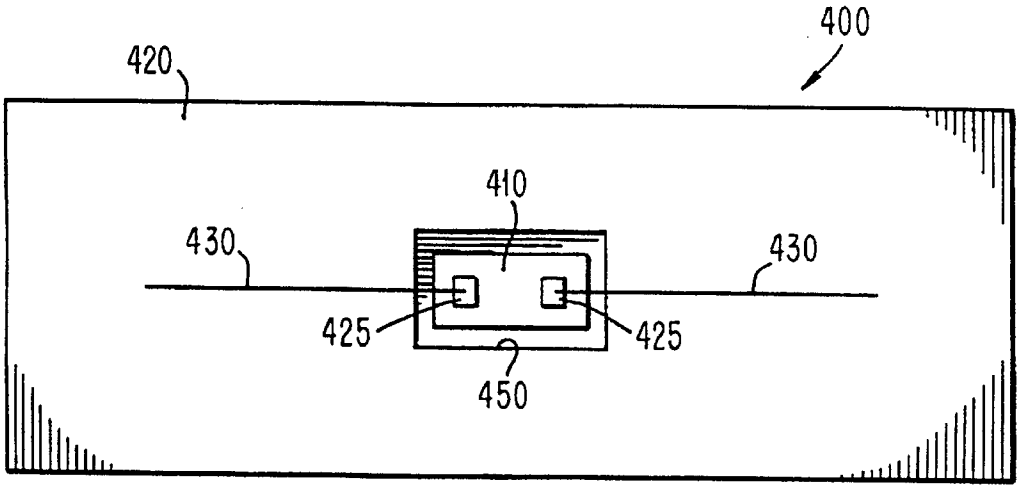
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FIG. 5

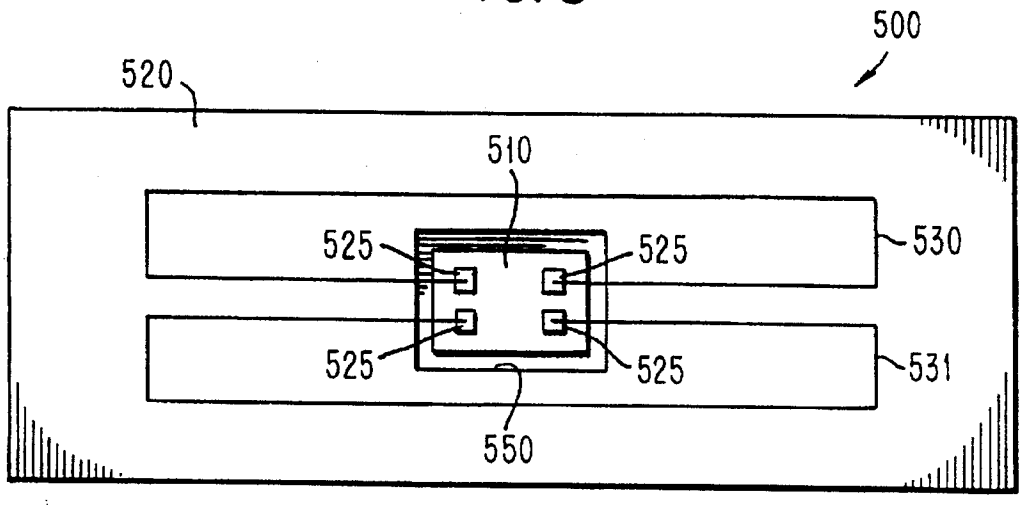
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FIG. 6

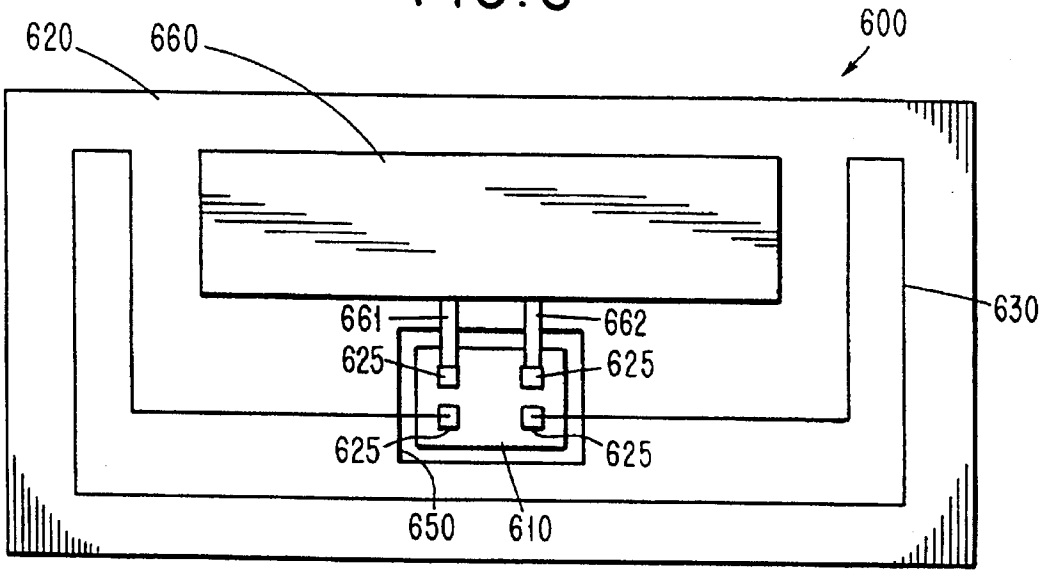


FIG. 7A PRIOR ART

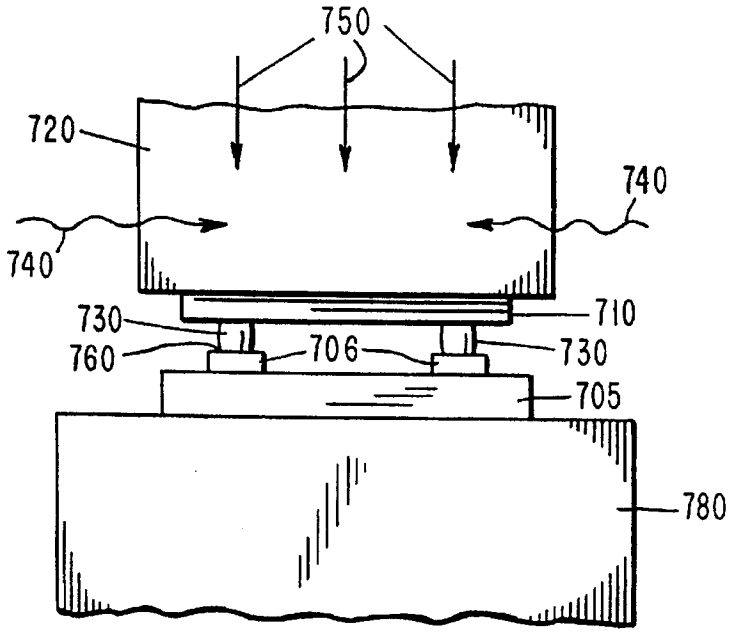


FIG. 7B
PRIOR ART

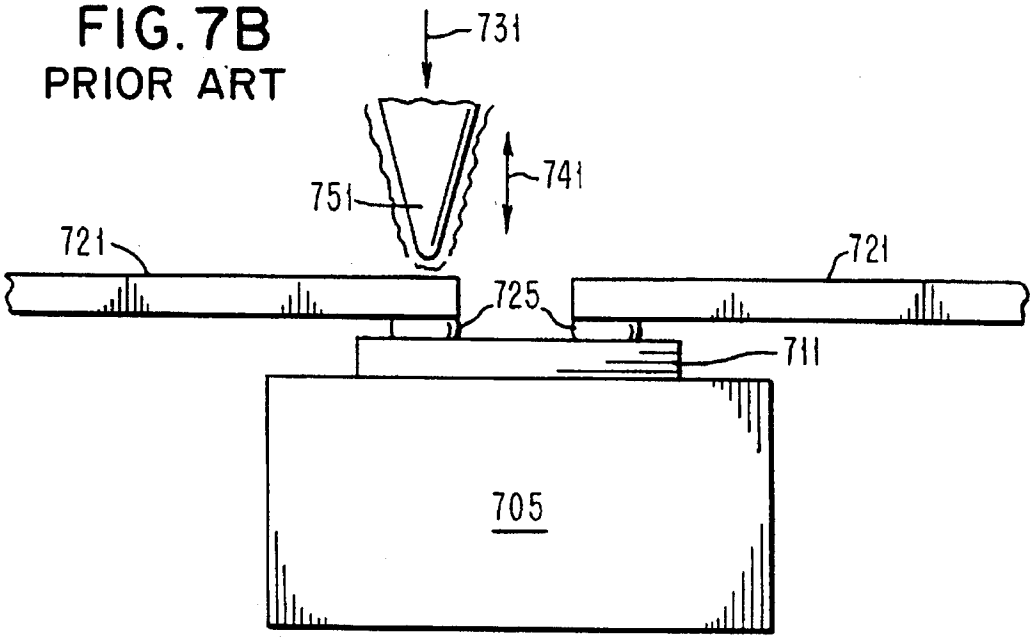


FIG. 7C
PRIOR ART

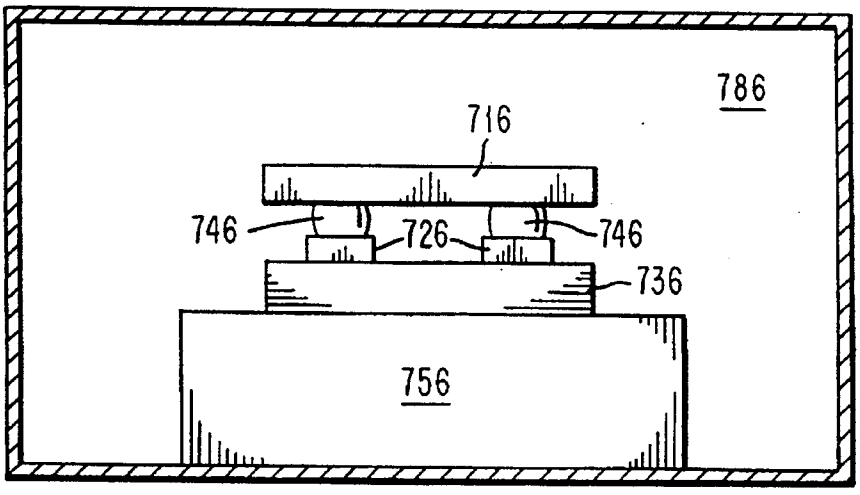


FIG. 7D
PRIOR ART

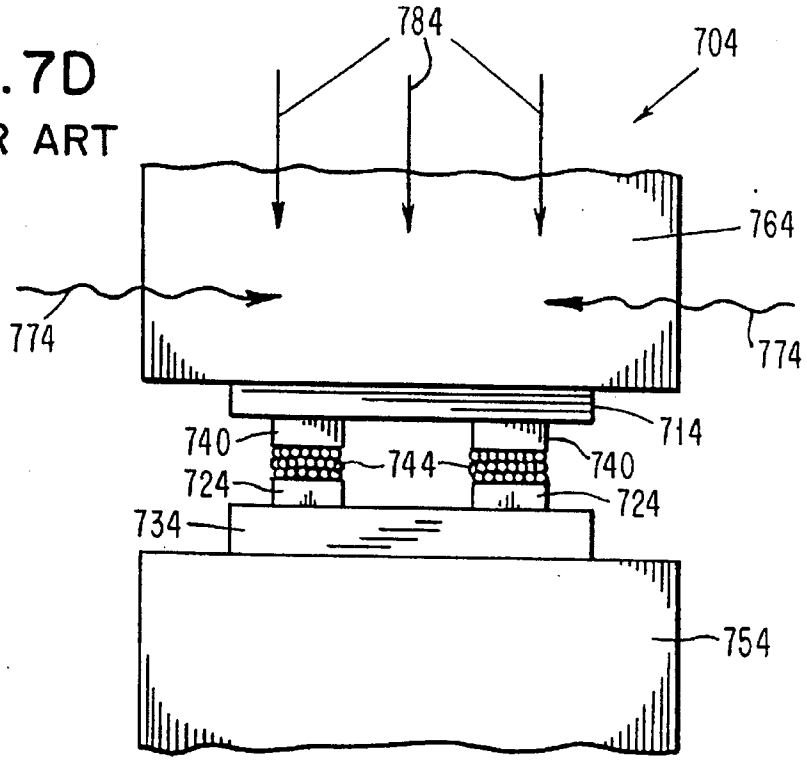


FIG. 7E
PRIOR ART

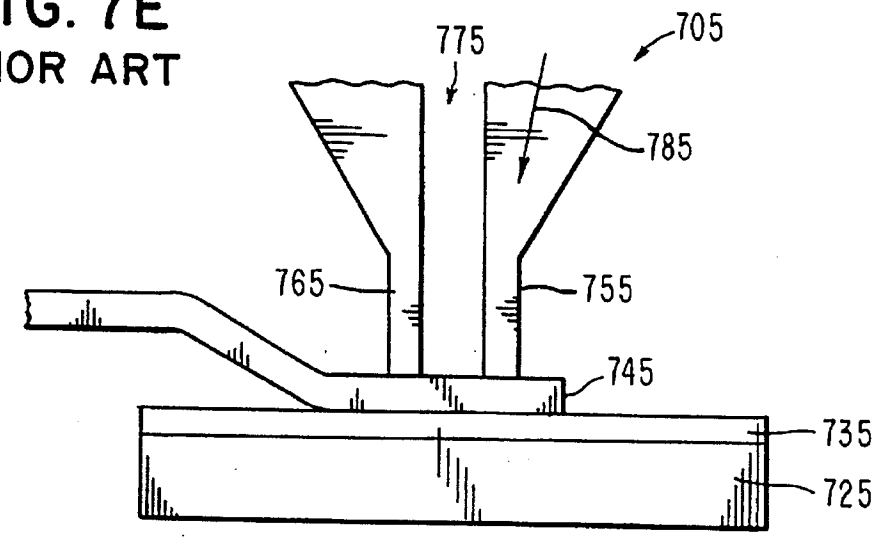


FIG. 8

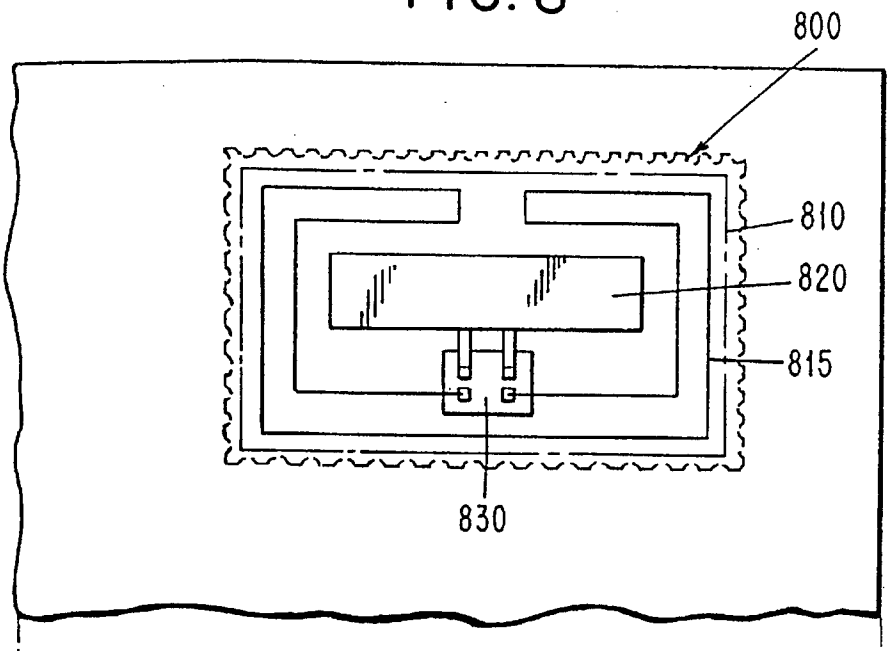


FIG. 8A

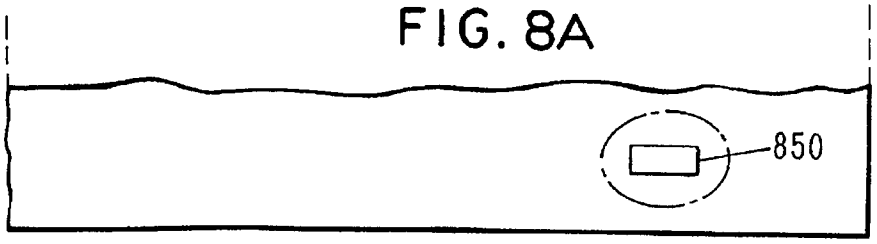


FIG. 9

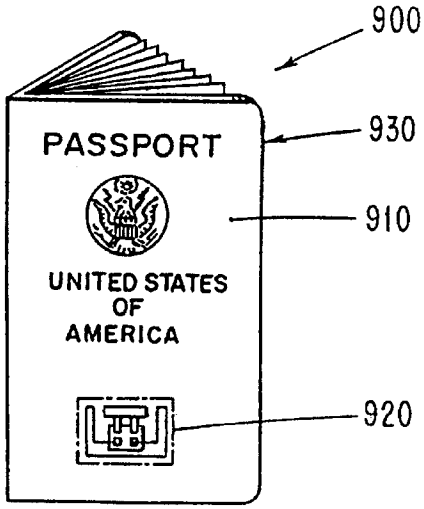


FIG. 10

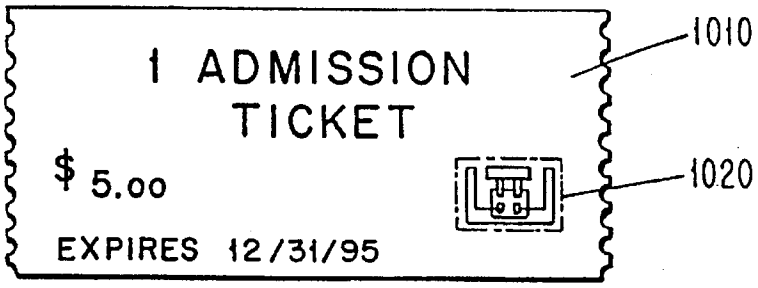
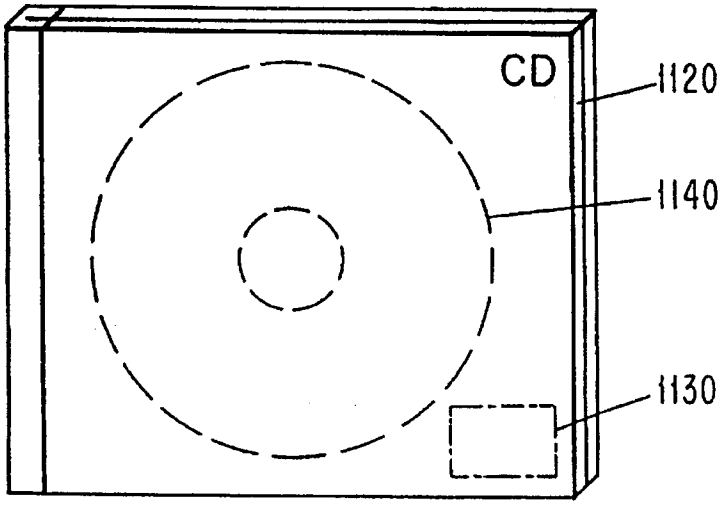

1 ADMISSION
TICKET
$ 5.00
EXPIRES 12/31/95
1010
1020

FIG. 11


CD
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1130

FIG. 12

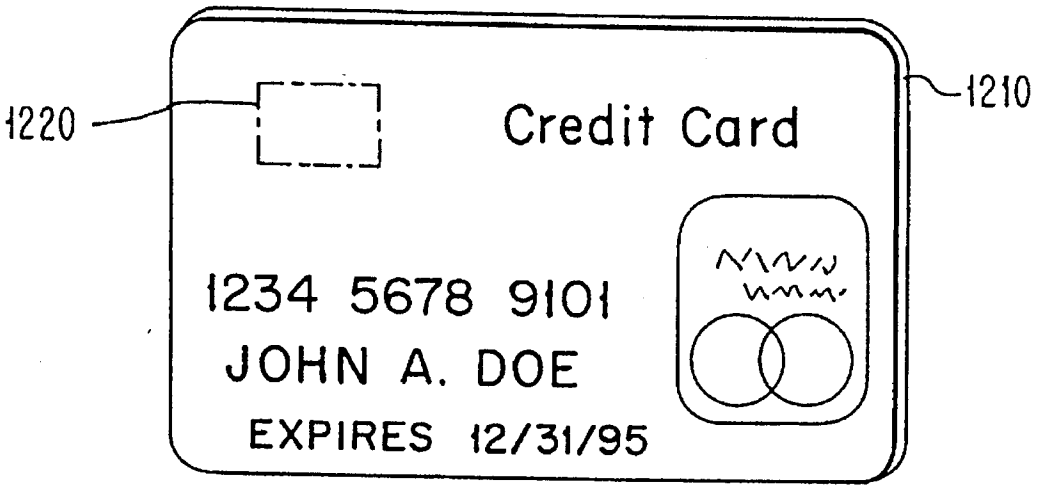
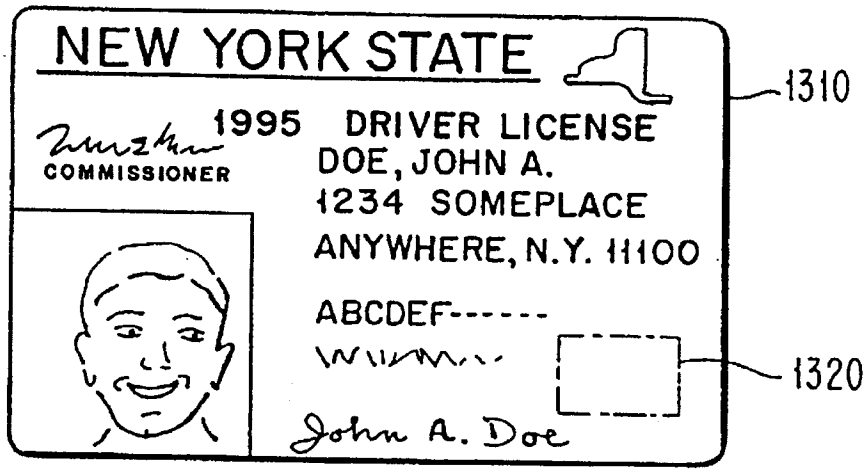

1220
Credit Card
1210
1234 5678 9101
JOHN A. DOE
EXPIRES 12/31/95

FIG. 13


NEW YORK STATE
1995 DRIVER LICENSE
COMMISSIONER
DOE, JOHN A.
1234 SOMEPLACE
ANYWHERE, N.Y. 11100
ABCDEF------
1310
1320
John A. Doe

RADIO FREQUENCY CIRCUIT AND MEMORY IN THIN FLEXIBLE PACKAGE

FIELD OF THE INVENTION

This invention relates to a radio frequency circuit and memory in a thin flexible package. More specifically, the invention relates to a thin flexible radio frequency circuit used as a radio frequency tag.

BACKGROUND OF THE INVENTION

Radio Frequency Identification (RF ID) is just one of many identification technologies for identifying objects. The heart of the RF ID system lies in an information carrying tag. The tag functions in response to a coded RF signal received from a base station. Typically, the tag reflects the incident RF carrier back to the base station. Information is transferred as the reflected signal is modulated by the tag according to its programmed information protocol.

The tag consists of a semiconductor chip having RF circuits, logic, and memory. The tag also has an antenna, often a collection of discrete components, capacitors and diodes, for example, a battery in the case of active tags, a substrate for mounting the components, interconnections between components, and a means of physical enclosure. One variety of tag, passive tags, has no battery. They derive their energy from the RF signal used to interrogate the tag. In general, RF ID tags are manufactured by mounting the individual elements to a circuit card. This is done by using either short wire bond connections or soldered connections between the board and the circuit elements: chip, capacitors, diodes, antenna. The circuit card may be of epoxy-fiberglass composition or ceramic. The antennas are generally loops of wire soldered to the circuit card or consist of metal etched or plated on a circuit card. The whole assembly may be enclosed in a plastic box or molded into a three dimensional plastic package.

While the application of RF ID technology is not as widespread as other ID technologies, bar code for example, RF ID is on its way to becoming a pervasive technology in some areas, notably vehicle identification.

Growth in RF ID has been inhibited by the high cost of tags, the bulkiness of most of the tags, and problems of tag sensitivity and range. A typical tag costs in the $5 to $10 range.

Companies have focused on niche applications. Some prior art is used to identify railway boxcars. These tags tend to be quite large and are made of discrete components on circuit boards mounted in solid, non-flexible casings. RF tags are now used in the automatic toll industry, e.g. on thruway and bridge tolls. RF tags are being tested for uses as contactless fare cards for buses. Employee identification badges and security badges have been produced. Animal identification tags are also commercially available as are RF ID systems for tracking components in manufacturing processes.

Tags exist that have the-length and width of a standard credit card. However, these cards typically are over 2.5 mm thick and have a non-flexible casing. Tags also exist that have a credit card size length and width but with bumps where circuit is placed that causes them to be too thick to fit in card reader machinery

While some electronic article surveillance (EAS), e.g. antitheft devices, are thin (0.3 mm) they typically contain limited amounts, (i.e., only one bit) of information. Some of these devices can be turned off once but cannot be reactivated.

FIG. 1A shows one prior art structure of a radio frequency tag **105**. The tag **105** has a chip **110** mounted on a substrate **115**. The chip **110** has contacts **120** that are connected to circuitry on the substrate **115** by wire bonds **125**. An encapsulation material **130** covers the chip for environmental protection. The thickness of this tag **105** is determined by the combined thicknesses of the chip components. Typically, substrates in these tags are at least 10 mils, 0.25 mm, in thickness, the chip **110** along with the high loop **122** of the bond vary from 20 to 40 mils, 0.5 to 1 mm, in thickness and the encapsulation **130** is about 10 mils, 0.25 mm in thickness. As a result, tags **105** of this structure vary from a minimum of 40 to 60 mils, 1 to 1.5 mm, in thickness. This structure is too thick for many potential tag applications.

FIG. 1B shows another prior art structure **150** showing a chip **110** with the chip contacts **120** connected to circuitry contacts **155** with conducting adhesive **160**. The substrate **165** of this structure **150** is typically made as a FR4/printed circuit (thickness 40 to 60 mils, 1 to 1.5 mm) or flexible substrate (10 mils,0.25 mm). The chip **110** and adhesive **160** add another 20 to 40 mils, 0.5 to 1 mm, to the thickness and the encapsulation **130** adds still another 10 to 20, 0.25 to 0.5 mm mils in structure **150** thickness. This structure therefore can vary in thickness from 80 to 130 mils, 2 to 3.5 mm, making it thicker than the structure in FIG. 1A.

Other thick structures are known in the art. These include quad flat pak (QFP) and/or small outline pak (SOP) as components. Structures made with these components are at least 1 mm thick and usually 2 to 3 mm thick.

PROBLEMS WITH THE PRIOR ART

Prior art teaches that there is a long felt need to manufacture thin RF ID tags on flexible substrates. However, while the goal of a thin flexible tag is desired, the prior art has failed to reach the goal. One prior art reference discloses a tag that is 1.5 to 2.0 mm thick. This tag thickness limits the applications of this tag. For example, it is far thicker than the International Organization for Standardization (ISO) standard credit card thickness of 0.76 mm and therefore could not be used in a credit card to be inserted into a credit card reader.

The prior art has failed to produce a thin tag because: care is not been taken to make each of the elements thin; elements are stacked one upon the next; and the antenna and connecting conductors require more than one plane of electrical wiring, ie. the designs use cross-overs for completing interconnections. As elements are stacked and layers are added the package grows thicker and flexibility is lost.

Another prior art reference discloses a package with a total thickness of 0.8 mm. This is still greater than the ISO standard credit card thickness of 0.76 mm. Furthermore, while thin elements are disclosed, no care is taken to use flexible materials throughout. The components are mounted on a hard circuit card and encapsulated in plastic. (Hard means can not be torn easily by hand.) The result a is rigid package. The prior art has not shown the use of thin flexible laminate covering materials for the packages. The results are that the packages are thick, and inflexible.

OBJECTS OF THE INVENTION

An object of this invention is an improved thin radio frequency tagging apparatus.

An object of the invention is a flexible radio frequency tag apparatus with a thin flexible protective lamination.

An object of the invention is a flexible radio frequency tag apparatus that may fit within the thickness limit of an ISO standard credit card, a passport cover, a postage stamp, an anti-theft device, or an admission ticket.

SUMMARY OF THE INVENTION

The present invention is a novel radio frequency (RF) tag that comprises a semiconductor circuit that has logic, memory, and radio frequency circuits. The semiconductor is mounted on a substrate and is capable of receiving a RF signal through an antenna that is electrically connected to the semiconductor through connections on the semiconductor. The present invention is a novel structure of a radio frequency tag design that is thin and flexible. The tag has the antenna and all interconnections placed on a single plane of wiring without crossovers. The elements of the package are placed adjacent to one another, i.e., they are not stacked. Elements of the package, the substrate, antenna, and laminated covers, are flexible. The elements are all thin such that the total package thickness including covers does not exceed that of an ISO standard credit card. The resulting tag package, comprised of thin, flexible components arranged and connected in a novel way, is also thin and flexible. Accordingly, this enables a novel range of applications that include: RF ID tagging of credit cards, passports, admission tickets, and postage stamps.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**, comprising FIGS. **1A** and **1B**, is a drawing showing the cross section view of two typical embodiments in the prior art.

FIG. **2** is drawing showing a cross section of one preferred embodiment of the present thin RF ID tag.

FIG. **3** is drawing showing a cross section of one preferred embodiment of the present thin RF ID tag with an aperture in the substrate.

FIG. **4** is a top view of the thin tag showing a dipole antenna.

FIG. **5** is a top view of a thin tag having more than one folded dipole antennas.

FIG. **6** is a top view of a thin tag having a battery included in the circuit.

FIG. **7** comprises FIGS. **7A–7E** which are cross sections of prior art chip bonds to substrates by means of thermocompression bonding (FIG. **7A**), ultrasonic bonding (FIG. **7B**), C4 solder bonding (FIG. **7C**), conducting adhesive bonding (FIG. **7D**), and spot welding (FIG. **7E**).

FIG. **8** shows a thin tag used as a postage stamp.

FIG. **8A** shows a thin tag enclosed in a parcel membrane or in the wall of an envelope.

FIG. **9** shows a thin tag placed in the cover of a passport using a resonant loop antenna.

FIG. **10** shows a thin tag used on an admission ticket.

FIG. **11** shows a thin tag used as an antitheft device.

FIG. **12** shows a thin tag placed inside a credit card.

FIG. **13** shows a thin tag placed inside a license.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **2** shows a side view of a novel RF ID tag **200**. The chip **210** is located on a flexible substrate **220**. The chip **210** with bumps **225** on contacts **222** is bonded to an antenna **230** contained on the substrate **220**. The package is sealed by thin flexible laminations **270** consisting of a hot-melt adhesive **250** such as EVA on the inside and an outer coating **260** of a tough polymeric material on the outside.

The antenna is manufactured as an integral part of the substrate. It will consist of thin, typically 25 to 35 micron thick copper lines which have either been etched onto a copper/organic laminate or plated on the organic surface. The thinness of the copper maintains the flexibility of the substrate. Typical materials used are polyester or polyimide for the organic and electroplated or rolled annealed copper. The copper may be gold or tin plated to facilitate bonding. The chip is connected to the antenna lines by means of bumps on the chip, either plated gold bumps for thermocompression bonding or C4 solder bumps for solder bonding are preferred. The bumps **225** then become the connecting lines. Since they are only on the order of 25 microns or so they will not degrade electrical performance by introducing unwanted inductance into the circuit. The novel design has a single metal layer with no vias (between-plane connectors through a dielectric layer) in the flexible continuous film. By using only one level of metal to produce the antenna and interconnections, the package is kept thin. Further novelty of the invention includes arranging the components (chip and antenna and possibly a battery) in adjacent proximity to one another. This means that the components are close (i.e., not stacked). In a more preferred embodiment the closeness is insured because the chip **210** is bonded directly to the antenna **230** without the use of crossovers in the circuit. This is accomplished by using either a dipole, loop or folded dipole antenna that is resonant rather than using a multiloop antenna which requires cross-overs for connection. Thus all of the wiring is placed in a single plane. Keeping the antenna adjacent to the chip, avoiding cross-overs and stacking, also contributes to keeping the package thin.

To maintain the thinness of the package, the chill is made to be 225 to 375 microns thick by thinning. In general, semiconductors are manufactured on thick wafers, up to 1 mm thick. Thinning may be done by polishing or backgrinding of the wafer after manufacture. All elements and bonds are very thin. The elements are preferably: the chip (and battery if used) are 10 to 12 mils (250 to 300 microns) thick or thinner; the bonding structures are 2 mils (50 um) or less; laminating materials 2 to 4 mils (50 to 125 um) per side; to produce total thickness preferably of about 20 mils (500 um) or less but in any case less than 30 mils (750 um). Bonding mechanisms do not add to thickness of the tag as would techniques like wirebonding.

Although not required in one preferred embodiment, a unique flexible covering material **270** may be laminated upon one or both sides of the package. In another preferred embodiment, the material consists of two layers (**250**, **260**). A soft copolymer such as ethyl-vinyl-acetate is located on the inside **250** surface of the cover. Tough polyester is located on the outside **260** surface. This combination provides environmental protection while maintaining the flexibility of the package. Typical thicknesses of the covers range from 50 to 125 microns. Alternately, a single layer of laminate such as polyethylene, polyester, mylar or polyimide may be used for covering.

FIG. **3** shows a side view of a unique RF ID tag **300**. The chip **310** with contacts **322** and bumps **325** is bonded to antenna **330** thru window **315** in substrate **320**. In a more preferred embodiment, encapsulant **340** is used to protect the chip **310**, the bonds **325** on contacts **322**, connected to antenna **330** located in window **315** between substrate **320** from environmental exposure. In a still more preferred

embodiment, the package is sealed by thin flexible laminations **370** consisting of hot melt adhesive **350** such as EVA, phenolic butyral, or silicone adhesive on the inside and an outer coating **360** of a tough polymeric material (such as polyester, mylar, polyimide, and polyethylene) on the outside. In an alternative preferred embodiment, layer **370** comprises a single layer of organic material.

In order to further reduce the thickness of the package, the substrate is manufactured with a window allowing the insertion of the chip into the window. Thus, the thickness of the substrate is not added to the thickness of the chip. The window is produced in organic materials, polyimide or polyester by either etching or punching. In addition, the window may be used to allow the coating of the chip with a thin layer of encapsulation material. Hysol epoxy **4510** is one such material. The encapsulant does not add substantially to the total package thickness, adding perhaps 50 microns, but does provide additional environmental protection for the chip. Opaque materials in the encapsulant protect light sensitive circuits on the chip. In this embodiment, the antenna and the center of the chip can be coplanar.

FIG. **4** shows a top view of the thin RF ID tag **400**. The chip **410** is located within a window **450** placed in a flexible substrate **420**. The chip **410** has contacts **425** which are connected to a antenna **430** contained on the substrate.

FIG. **5** shows a top view of the thin RF ID tag **500**. The chip **510** placed in the window **550** has contacts **525** which are connected to more than one folded dipole antenna **530** and **531** contained on the substrate.

FIG. **6** shows a top view of the thin tag **600**. The semiconductor chip **610** is connected to a folded dipole antenna **630** by means of contacts **625**. The antenna is contained in the substrate **620** as described above. A thin battery **660** is connected to the chip **610** by leads **661** and **662** bonded at contacts **625**.

The battery has short connecting lines **661** and **662** providing electrical continuity between the battery and the chip. The battery is placed adjacent to the chip, not stacked upon the chip. The battery thickness of about 0.25 mm keeps the battery flexible. The antenna is designed such that it is also adjacent to the battery. There is no overlap. The wiring is kept in one plane and all of the elements (chip, battery, antenna) are coplanar; there is no stacking. As a result, the package is thin and flexible.

The bonding method for attaching batteries to prior art radio frequency tags include some of the techniques described below, i.e., soldering, conducting adhesive; and wire bonding. In addition, spot welding may be used. In spot welding, shown below in FIG. **7E**, the battery connection pads are pressed to contacts on the substrate while a low-voltage high-current pulse bonds the two metals together.

In one preferred embodiment, the metallurgies on the battery, chip, and substrate are such that the battery attaching mechanism is consistent with the method and mechanism of the chip attachment. For example, use of tin plating on the substrate to enable chip bonding may preclude use of conductive adhesive to attach the battery but might allow use of gold plating to enable attaching of both.

A more preferred embodiment used to make a thin flexible rugged package uses robust chip attach techniques such as thermocompression (TC) bonding used in TAB (tape automated bonding) technology. Using TC bonding for the chip and spot welding for the battery is a novel combination of bonding techniques that enables attachment of the battery to a flexible substrate **620**. In one preferred embodiment, the substrate is a TAB polyimide or polyester.

FIG. **7** shows different types of bonding available in the prior art to attach chips to circuitry that are on the substrate when producing an RF tag. These include thermocompression bonding, ultrasonic single point bonding, soldering, and conductive adhesive.

In FIG. **7A**, using thermocompression bonding, suitable metal surfaces are brought into contact with pressure **750** and heat **740** applied by thermode **720** to form a metal-to-metal bond **760** usually gold bumps **730** on chip **710** to gold-plated leads **706** on substrate **705** which rests on lower thermode **780**. Many leads are bonded at once (gang bonding). This is used extensively for reel-to-reel TAB (tape automated bonding).

FIG. **7B** shows ultrasonic singlepoint bonding a variation on thermocompression bonding for TAB where some ultrasonic energy is substituted for some pressure. One bond is done at a time. This bonding type also requires gold-to-gold metallurgy. Bonding tip **751** applies pressure **731** and ultrasonic energy **741** while pressing lead **721** to bump **725** on chip **711** resting on lower support **705**.

FIG. **7C** shows soldering or C4 solderbonding where small lead/tin solder bumps **746** are used as the connecting medium between chip **716** and pads **726** on substrate **736**. The reflow is carried out while the substrate is carried on platform **756** through oven **786**. This usually requires the application of solder flux for reflow of the solder at elevated temperature.

FIG. **7D** shows conducting adhesive bonding where a metal-filled adhesive **744** is applied to form the connecting medium between chip pads **740** on chip **714** and the substrate pads **724** on the substrate **734**. Heat **774** and pressure **784** are applied by pressing between thermodes **764** and **754**.

FIG. **7E** shows spot welding where welding tips **755** and **765** separated by gap **775** are pressed to conductor **745** held in contact with conductor **735** placed on insulating substrate **725**. Current **785** heats the welding tips **755** and **765** to make the bond.

FIG. **8** shows an RF postage stamp **800** containing a thin RF tag **810** which consists of antenna **815**, battery **820**, and chip **830** affixed to envelope or package **840**. This tag **810** can be any of the embodiments described above. In this application, the cover (typically **270** of FIG. **2** and **370** of FIG. **3**) for the tag is the paper of the stamp. Adhesives, such as acrylics, are used to sandwich the tag between thin paper. These adhesives would correspond to the layer **250** in FIG. **2** and **350** in FIG. **3**. The top surface (of one side **270**, **370**) can be printed with the appropriate graphics while the bottom surface has a pressure sensitive adhesive (of the other side **270**, **370** in the case of a tag laminated on two sides), also acrylic, to bond the stamp to a package or letter envelope. The RF tag would contain information about mailing used to track a letter or parcel on which the stamp is placed. Alternatively, the RF tag **850** could be enclosed in the parcel membrane or in the wall of the envelop **840**. In another, embodiment the RF tag could be placed within the parcel or envelop.

FIG. **9** shows the thin RF tag **920** embedded in the cover **910** of passport **930** to form an RF passport **900**. Here the tag is sandwiched between the paper covers of the passport. The tag can have an environmental laminate(s) (**270**, **370**) as described above or alternatively, the passport cover can be used as the tag laminate(s) (**270**, **370**). The tag contains in its memory information on the identity of the passport owner, visas, dates of entry, restrictions, or any other desirable information. The information may be in encrypted form for added security. The encryption "key" would be a software

code that is held and used solely by the agency issuing the passport. The deencryption key may be made public so that anyone (with a public deencryption key) can read information in the memory of the tag but only the agency having the encryption key can write information to the tag.

FIG. **10** shows admission ticket **1010** containing RF tag **1020**. The tag is again enclosed between paper covers or other laminates. The ticket may be a simple admission ticket or entitlement such as an airline ticket or a food stamp. However, the tagged ticket may also serve as a tracking device.

FIG. **11** shows a CD **1140** enclosed in box **1120** with an RF ID antitheft tag **1130** affixed to the box **1120**. The tag serves as both a barcode replacement, inventory device, point of sale device, and as an antitheft device. Information on product variety, price, date of manufacture and sale may be carried by the tag. Additional bits of information in the memory of the circuit may be changed at the time of sale to indicated that the item may be taken from the store.

FIG. **12** shows ISO standard credit card **1210** containing an RF tag **1220**. The credit card may serve as an ATM card, frequent flyer card, library card, phone card, employee ID, medical ID card, gasoline credit card or any credit or debit card. The covers (laminates **270, 370**) of the tag could be the covers of the credit card, preferably PVC laminations. The core of the credit card, 0.5 mm thick, has a window placed in it at the time of manufacture. The 0.5 mm thick tag package is placed in the window and then sealed into the card. The resulting credit card, including the tag, will not only have the length and width that meet the ISO standard, but the thickness as well.

In another embodiment of the present invention, shown in FIG. **13**, the RF tag **1320** is place within a vehicular drivers license **1310** in the same manner as described above. This allows information on the RF tag to be used for personal identification, driving record, organ donor information, restrictions, proof of identity and age, etc. The information can be encrypted for security purposes.

We claim:

1. A thin flexible electronic radio frequency tag circuit comprising;

a. an insulating, flexible substrate;

b. an antenna that is an integral part of the substrate and that has terminals;

c. a circuit chip having a modulator circuit, a logic circuit, a memory circuit, and chip connectors and being on the substrate in adjacent proximity to the antenna;

d. one or more connecting lines between the antenna terminals and the chip connectors, the connecting lines being coplanar with the antenna and antenna terminals.

2. A circuit, as in claim **1**, wherein the substrate is organic.

3. A circuit, as in claim **2**, wherein the substrate is polyimide.

4. A circuit, as in claim **2**, wherein the substrate is polyester.

5. A circuit, as in claim **1**, wherein the connecting lines are bonded to the chip connectors using any of the bonding types including thermal compression, single point bonding, C4 bonding, and conductive adhesive.

6. A circuit, as in claim **1**, wherein the substrate has an aperture into which the chip is placed.

7. A circuit, as in claim **1**, wherein the chip is covered by an encapsulant.

8. A circuit, as in claim **7**, wherein the encapsulant is opaque.

9. A circuit, as in claim **7**, wherein an organic cover surrounds the chip, the encapsulant, the substrate, and the antenna.

10. A circuit, as in claim **9**, wherein the organic cover is one of the materials including polyester, mylar, polyimide, and polyethylene.

11. A circuit, as in claim **1**, that is laminated by one or more layers.

12. A circuit, as in claim **11**, that is laminated by a two layer laminate comprising a hard outer layer and a adhesive inner layer.

13. A circuit, as in claim **12**, wherein the adhesive is one of the materials including ethyl vinyl acetate (EVA), phenolic butyral, and silicone adhesive.

14. A circuit, as in claim **11**, wherein the circuit is laminated on one side.

15. A circuit, as in claim **11**, wherein the circuit is laminated on two sides.

16. A circuit, as in claim **11**, wherein the circuit has at least one tag dimension that is less than 760 microns (30 mils).

17. A circuit, as in claim **16**, that is encapsulated as an International Organization for Standardization (ISO) standard credit card size package.

18. A circuit, as in claim **1**, wherein the antenna is a resonant antenna and is any one of the following structures including folded dipole, dipole, and loop.

19. A circuit, as in claim **1**, wherein a battery is also affixed to the substrate in adjacent proximity to the antenna and chip and is connected by one or more battery connecting lines to two or more chip battery contacts wherein the battery connecting lines and the battery contacts are coplanar with the antenna and connecting lines.

20. A circuit, as in claim **19**, wherein the battery contacts are connected to the battery connecting lines by any of the bonding types including spot welding, soldering, thermocompression bonding, and conducting adhesive.

21. A circuit, as in claim **19**, wherein the battery contacts are connected by spot welding and the chip contacts are connected to the antenna by thermocompression bonding.

22. A circuit, as in claim **1**, wherein the chip has at least one chip dimension less than 300 microns (12 mils), the antenna has at least one antenna dimension less than 35 microns (1.4 mils), and the substrate has at least one substrate dimension less than 125 microns (5 mils) whereby the circuit has at least one circuit dimension less than 508 microns (20 mils).

23. A circuit, as in claim **22**, wherein the chip memory has information about mailing and the circuit is applied to a mailed letter or parcel.

24. A circuit, as in claim **23**, wherein the RF tag is enclosed within a stamp.

25. A circuit, as in claim **23**, wherein the RF tag is enclosed within the parcel or envelop membrane.

26. A circuit, as in claim **22**, wherein the tag is enclosed in a passport.

27. A circuit, as in claim **22**, wherein the tag is enclosed in an admission ticket.

28. A circuit, as in claim **22**, that is enclosed in an article and the tag has information to prevent theft.

29. A circuit, as in claim **22**, wherein the tag is enclosed in a drivers license.

* * * * *

EXHIBIT B

US005777561A

United States Patent [19]

Chieu et al.

[11] Patent Number: 5,777,561

[45] Date of Patent: Jul. 7, 1998

[54] **METHOD OF GROUPING RF TRANSPONDERS**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **720,598**

[22] Filed: **Sep. 30, 1996**

[51] **Int. Cl.**[6] **H04Q 1/00**

[52] **U.S. Cl.** **340/825.54**; 342/42

[58] **Field of Search** 340/825.54, 572, 340/573; 342/42

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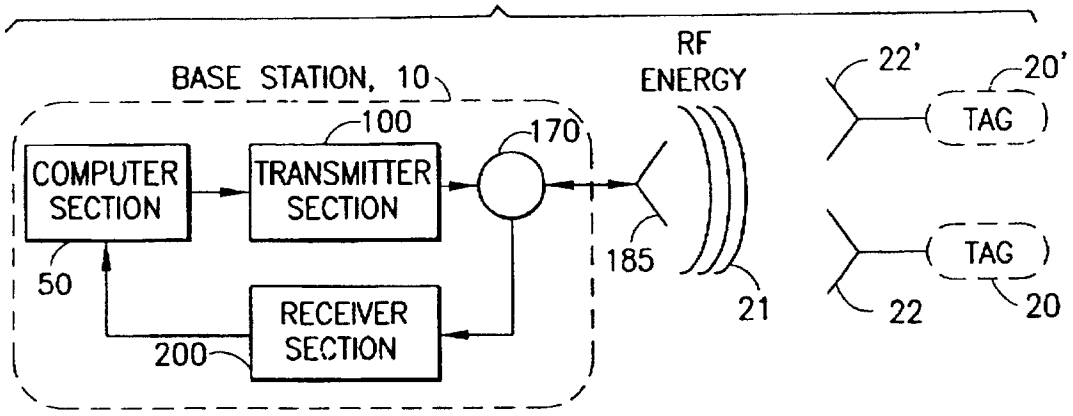
Primary Examiner—Brian Zimmerman

Attorney, Agent, or Firm—Rodney T. Hodgson

[57] **ABSTRACT**

A method of selecting groups of radio frequency RF transponders (tags) for communication between a base station and the tags. The tags are selected into groups according to a physical attribute ofthe signal sent by the tags to the base station, or according to the physical response of the tags to a physical attribute of the signal sent from the base station to the tags. Communication with the tags is thereby simplified, and the time taken to communicate with the first tag is markedly reduced.

28 Claims, 7 Drawing Sheets



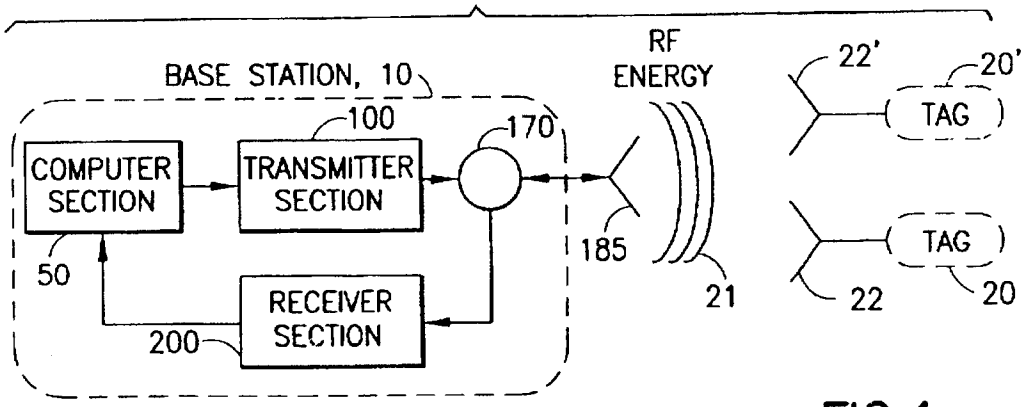


FIG.1

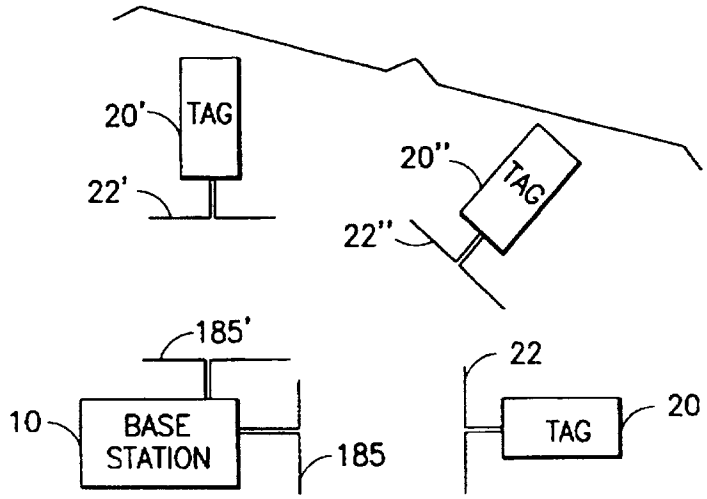


FIG.2

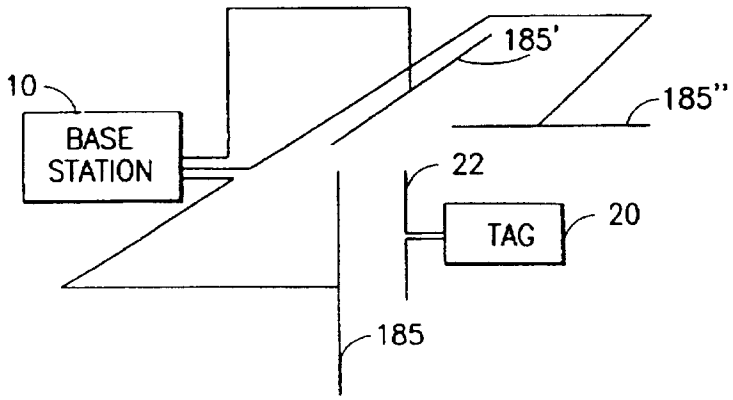


FIG.3

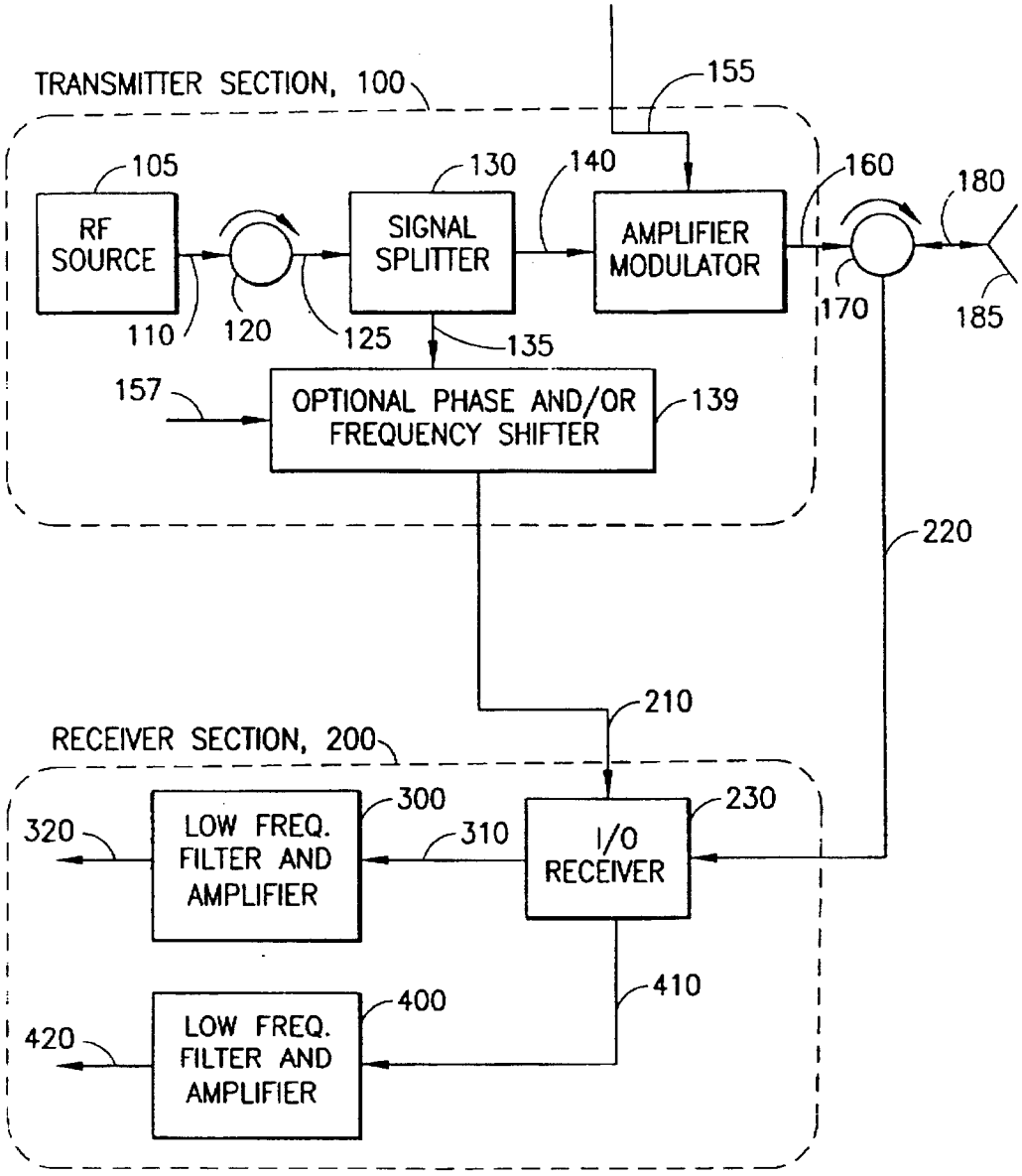

TRANSMITTER SECTION, 100
155
105
RF SOURCE
110
120
125
130
SIGNAL SPLITTER
135
140
AMPLIFIER MODULATOR
157
OPTIONAL PHASE AND/OR FREQUENCY SHIFTER
139
160
170
180
185
220
210
RECEIVER SECTION, 200
300
LOW FREQ. FILTER AND AMPLIFIER
310
320
230
I/O RECEIVER
410
400
LOW FREQ. FILTER AND AMPLIFIER
420

FIG.4

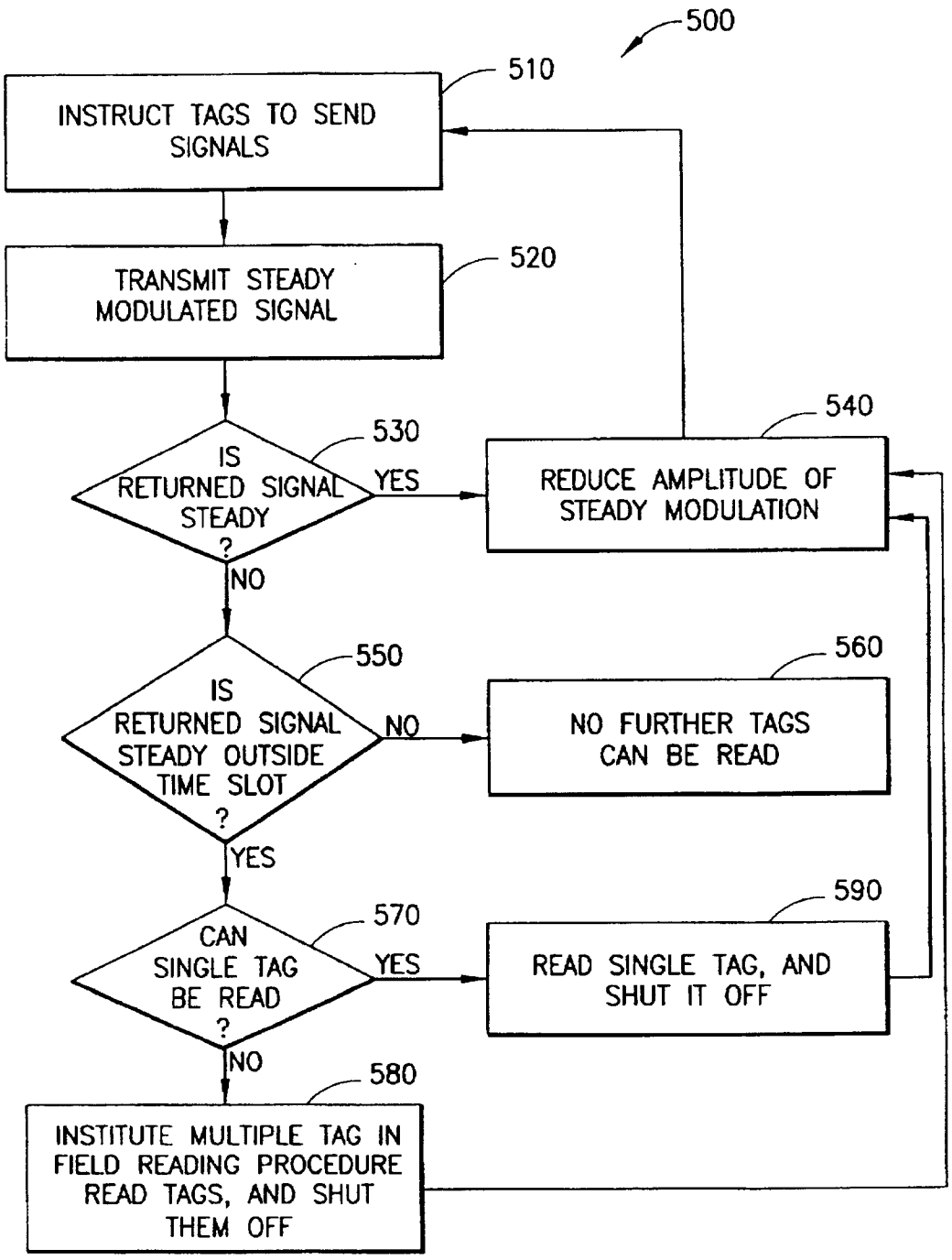

500
510
INSTRUCT TAGS TO SEND SIGNALS
520
TRANSMIT STEADY MODULATED SIGNAL
530
IS RETURNED SIGNAL STEADY ?
YES
540
REDUCE AMPLITUDE OF STEADY MODULATION
NO
550
IS RETURNED SIGNAL STEADY OUTSIDE TIME SLOT ?
NO
560
NO FURTHER TAGS CAN BE READ
YES
570
CAN SINGLE TAG BE READ ?
YES
590
READ SINGLE TAG, AND SHUT IT OFF
NO
580
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE READ TAGS, AND SHUT THEM OFF

FIG.5

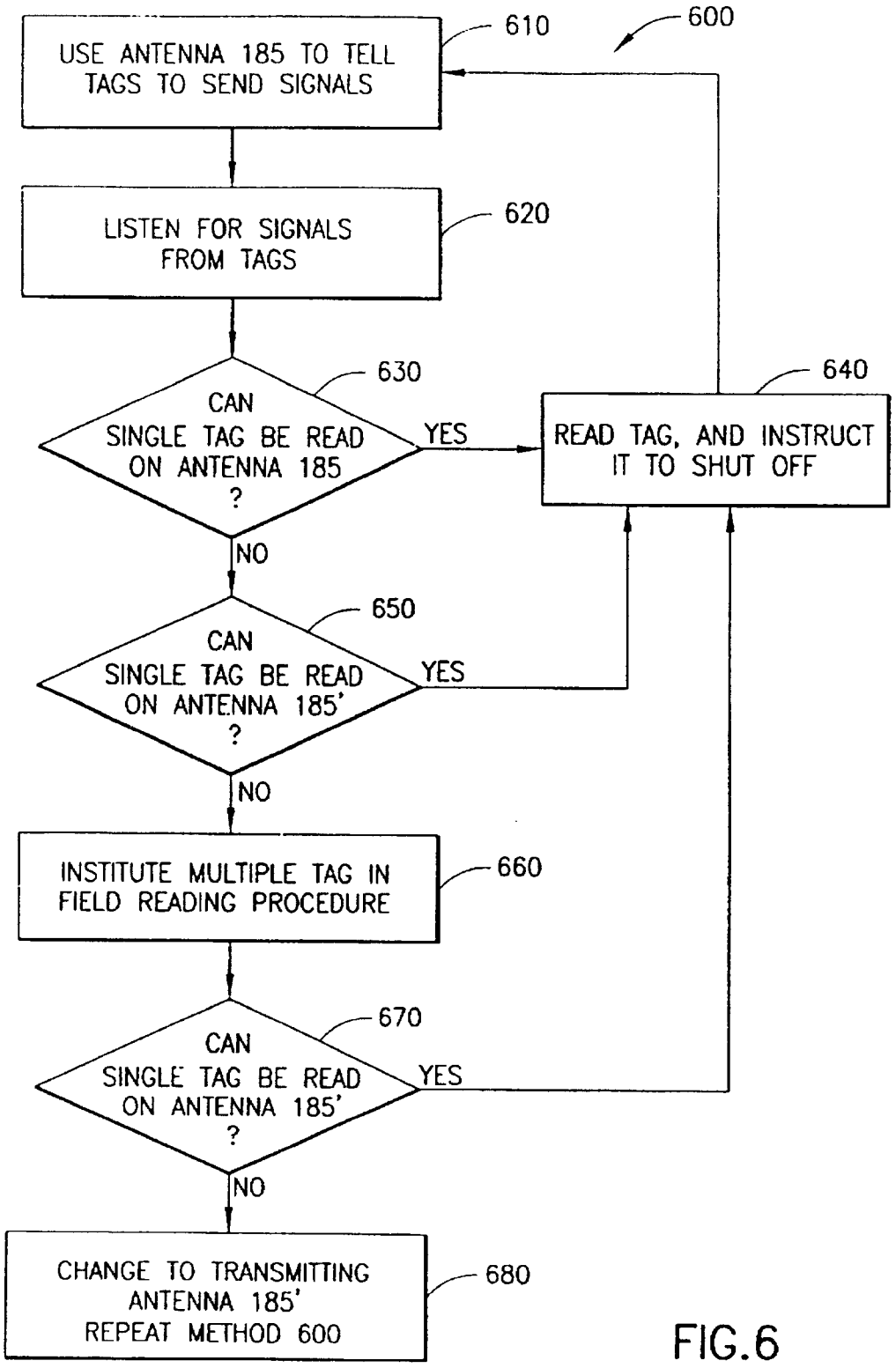

600
610
USE ANTENNA 185 TO TELL TAGS TO SEND SIGNALS
620
LISTEN FOR SIGNALS FROM TAGS
630
CAN SINGLE TAG BE READ ON ANTENNA 185 ?
YES
640
READ TAG, AND INSTRUCT IT TO SHUT OFF
NO
650
CAN SINGLE TAG BE READ ON ANTENNA 185' ?
YES
NO
660
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
670
CAN SINGLE TAG BE READ ON ANTENNA 185' ?
YES
NO
680
CHANGE TO TRANSMITTING ANTENNA 185' REPEAT METHOD 600

FIG.6

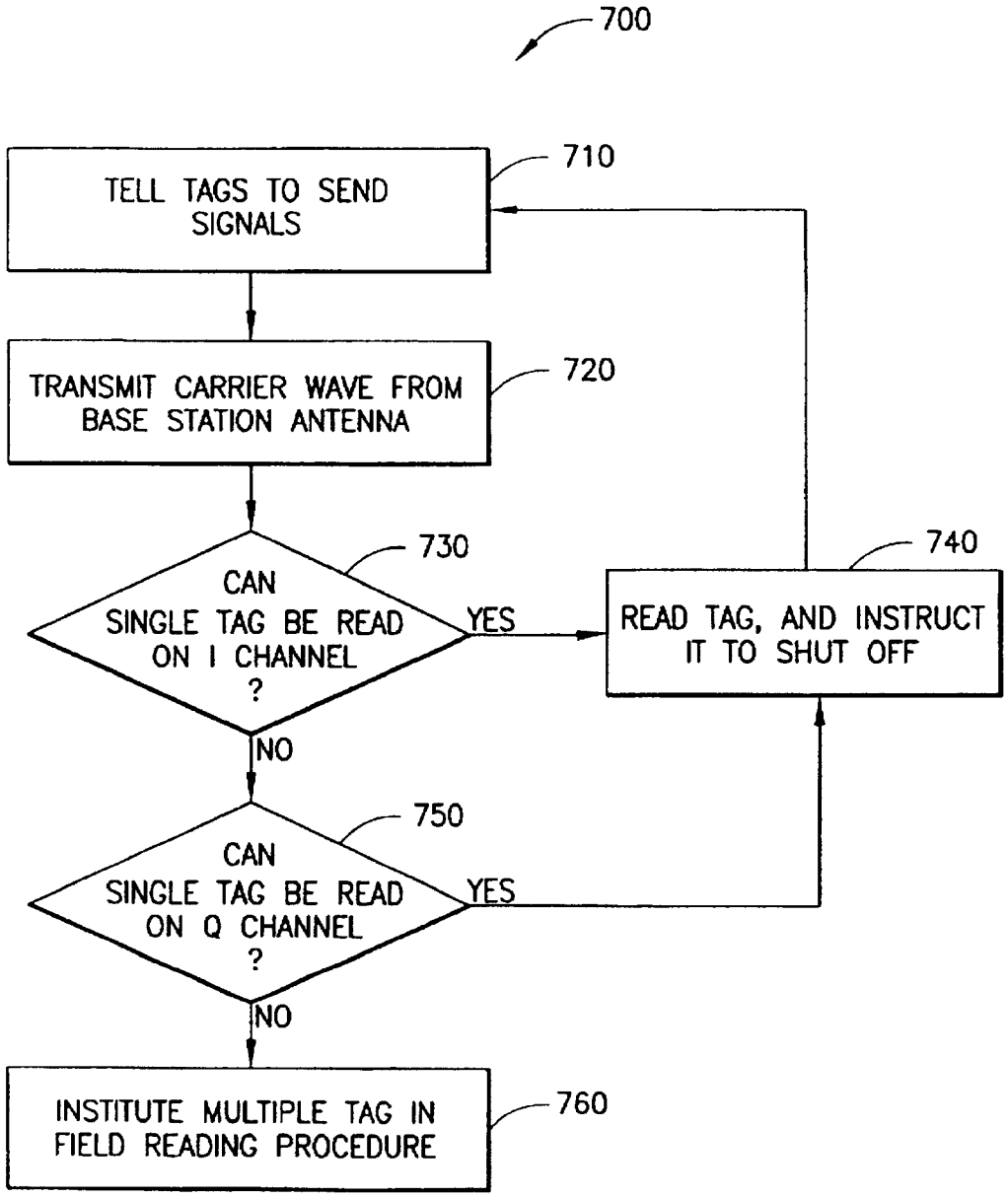

700
TELL TAGS TO SEND SIGNALS
710
TRANSMIT CARRIER WAVE FROM BASE STATION ANTENNA
720
CAN SINGLE TAG BE READ ON I CHANNEL ?
730
YES
READ TAG, AND INSTRUCT IT TO SHUT OFF
740
NO
CAN SINGLE TAG BE READ ON Q CHANNEL ?
750
YES
NO
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
760

FIG.7

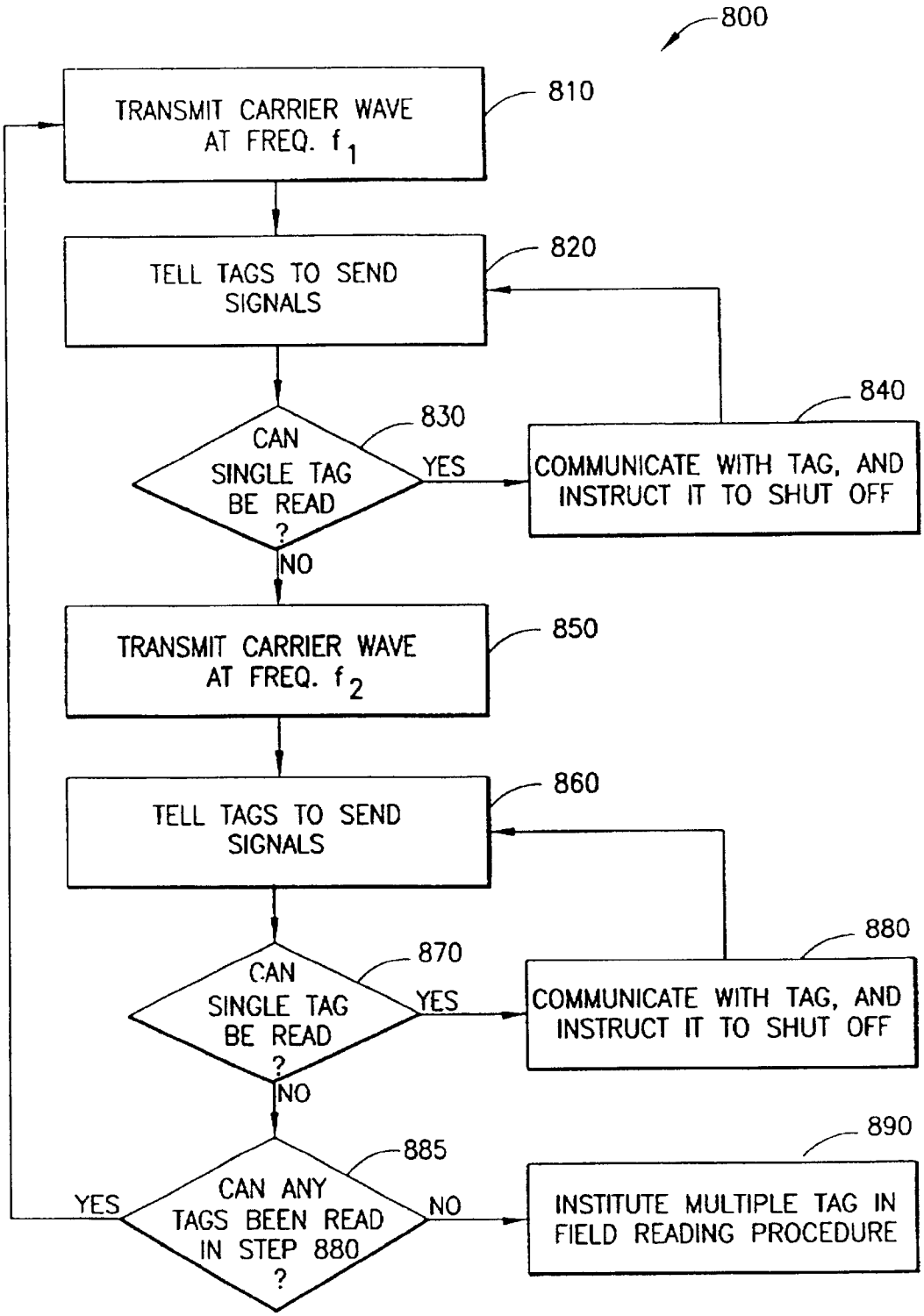

800
TRANSMIT CARRIER WAVE AT FREQ. f_1
810
TELL TAGS TO SEND SIGNALS
820
CAN SINGLE TAG BE READ ?
830
YES
COMMUNICATE WITH TAG, AND INSTRUCT IT TO SHUT OFF
840
NO
TRANSMIT CARRIER WAVE AT FREQ. f_2
850
TELL TAGS TO SEND SIGNALS
860
CAN SINGLE TAG BE READ ?
870
YES
COMMUNICATE WITH TAG, AND INSTRUCT IT TO SHUT OFF
880
NO
CAN ANY TAGS BEEN READ IN STEP 880 ?
885
YES
NO
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
890

FIG.8

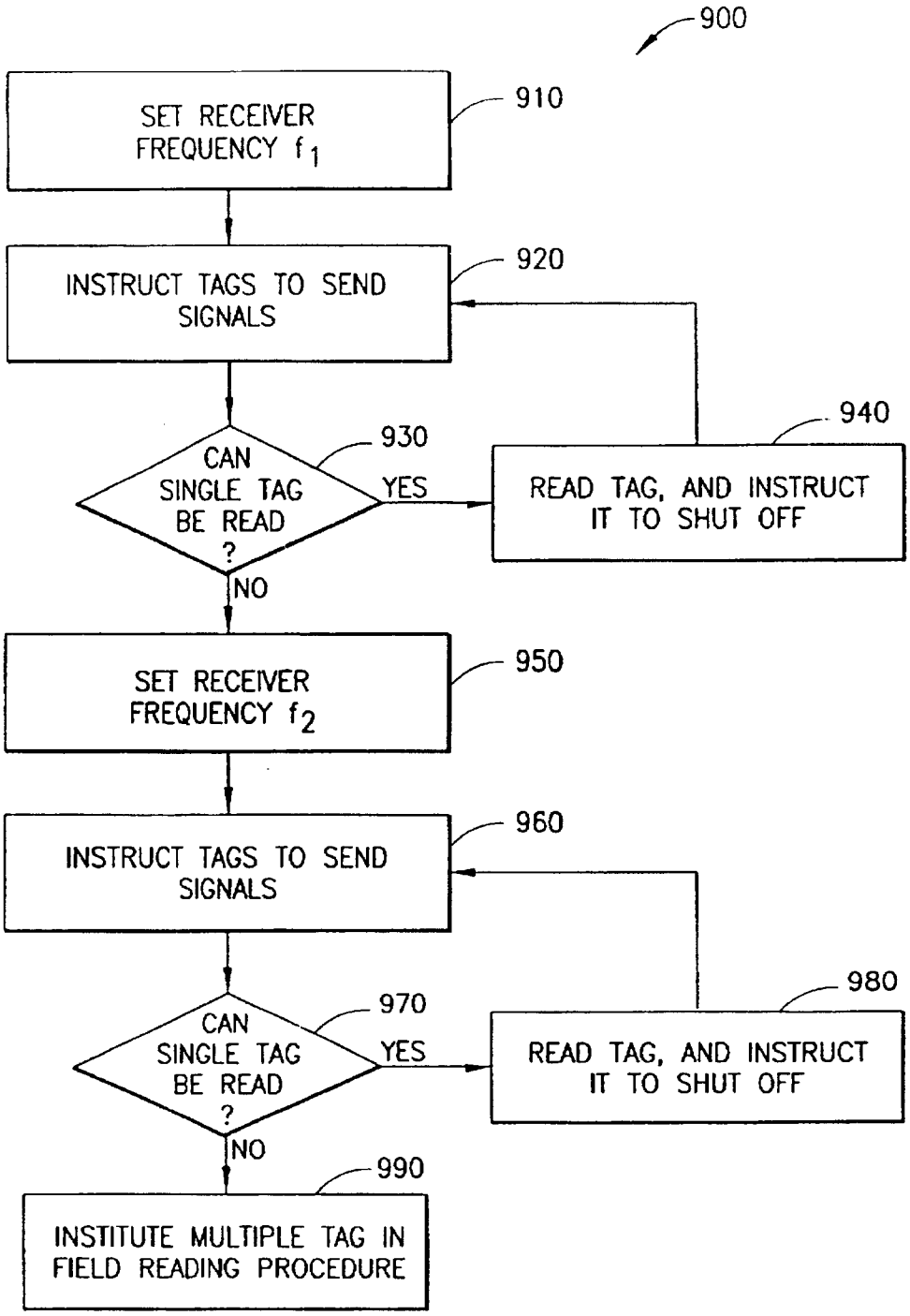

900
SET RECEIVER FREQUENCY f_1
910
INSTRUCT TAGS TO SEND SIGNALS
920
CAN SINGLE TAG BE READ ?
930
YES
READ TAG, AND INSTRUCT IT TO SHUT OFF
940
NO
SET RECEIVER FREQUENCY f_2
950
INSTRUCT TAGS TO SEND SIGNALS
960
CAN SINGLE TAG BE READ ?
970
YES
READ TAG, AND INSTRUCT IT TO SHUT OFF
980
NO
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
990

FIG.9

METHOD OF GROUPING RF TRANSPONDERS

FIELD OF THE INVENTION

The field of the invention is the field of Radio Frequency (RF) Transponders (RF Tags), wherein a Base Station sends power and information to one or more RF Tags which contain logic and memory circuits for storing information about objects, people, items, or animals associated with the RF Tags. The RF Tags can be used for identification and location (RFID Tags) of objects and to send information to the base station by modulating the load on an RF Tag antenna.

BACKGROUND OF THE INVENTION

RF Tags can be used in a multiplicity of ways for locating and identifying accompanying objects, items, animals, and people, whether these objects, items, animals, and people are stationary or mobile, and transmitting information about the state of the of the objects, items, animals, and people. It has been known since the early 60's in U.S. Pat. No. 3,098,971 by R. M. Richardson, that electronic components on a transponder could be powered by radio frequency (RF) power sent by W a "base station" at a carrier frequency and received by an antenna on the tag. The signal picked up by the tag antenna induces an alternating current in the antenna which can be rectified by an RF diode and the rectified current can be used for a power supply for the electronic components. The tag antenna loading is changed by something that was to be measured, for example a microphone resistance in the cited patent. The oscillating current induced in the tag antenna from the incoming RF energy would thus be changed, and the change in the oscillating current led to a change in the RF power radiated from the tag antenna. This change in the radiated power from the tag antenna be picked up by the base station antenna and thus the microphone would in effect broadcast power without itself having a self contained power supply. In the cited patent, the antenna current also oscillates at a harmonic of the carrier frequency because the diode current contains a doubled frequency component, and this frequency can be picked up and sorted out from the carrier frequency much more easily than if it were merely reflected. Since this type of tag carries no power supply of its own, it is called a "passive" tag to distinguish it from an active tag containing a battery. The battery supplies energy to run the active tag electronics, but not to broadcast the information from the tag antenna. An active tag also changes the loading on the tag antenna for the purpose of transmitting information to the base station.

The "rebroadcast" of the incoming RF energy at the carrier frequency is conventionally called "back scattering", even though the tag broadcasts the energy in a pattern determined solely by the tag antenna and most of the energy may not be directed "back" to the transmitting antenna.

In the 70's, suggestions to use tags with logic and read/write memories were made. In this way, the tag could not only be used to measure some characteristic, for example the temperature of an animal in U.S. Pat. No. 4,075,632 to Baldwin et. al., but could also identify the animal. The antenna load was changed by use of a transistor.

Prior art tags have used electronic logic and memory circuits and receiver circuits and modulator circuits for receiving information from the base station and for sending information from the tag to the base station.

The continuing march of semiconductor technology to smaller, faster, and less power hungry has allowed enormous

increases of function and enormous drop of cost of such tags. Presently available research and development technology will also allow new function and different products in communications technology.

U.S. Pat. No. 5,214,410, hereby incorporated by reference, teaches a method for a base station to communicate with a plurality of Tags . The tags having a particular code are energized, and send a response signal at random times. If the base station can read a tag unimpeded by signals from other tags, the base station interrupts the interrogation signal, and the tag which is sending and has been identified shuts down. The process continues until all tags in the field have been identified. If the number of possible tags in the field is large, this process can take a very long time. The average time between the random responses of the tags must be set very long so that there is a reasonable probability that a tag can communicate in a time window free of interference from the other tags.

RELATED APPLICATIONS

Copending patent applications assigned to the assignee of the present invention and hereby incorporated by reference, are:

- Ser. No. 08/303,965 filed Sep. 9, 1994 entitled RF Group Select Protocol, by Cesar et. al. now U.S. Pat. No. 5,673,037;
- Ser. No. 08/304,340 filed Sep. 9, 1994 entitled Multiple Item RF ID protocol, by Chan et. al. now U.S. Pat. No. 5,550,547;
- Ser. No. 08/521,898 filed Aug. 31, 1995 entitled Diode Modulator for RF Transponder by Friedman et al. now U.S. Pat. No. 5,606,323;
- application submitted Aug. 9, 1996 entitled RFID System with Broadcast Capability by Cesar et al.; and
- application submitted Jul. 29, 1996 entitled RFID transponder with Electronic Circuitry Enabling and Disabling Capability, by Heinrich et al.

These applications teach a communications protocol whereby a base station communicates to a plurality of tags by polling the tags and shutting down tags in turn until there is just one left. The information is then exchanged between the base station and the one tag, and then the one tag is turned off The unidentified tags are then turned on, and the process is repeated until all the tags have the communication protocol completed. Typical protocols requires a time which is not linearly proportional to the number oftags in the field. More tags take a longer time per tag than fewer tags. If the tags can be selected into groups in some way, each group can be dealt with in a shorter time per tag, and the time taken to communicate with the first tag is markedly shortened.

SUMMARY OF THE INVENTION

The method of the present invention is a method of selecting groups of RF tags for a communication protocol comprising selecting a plurality of groups of tags according to a physical attribute of the signal sent by the tags to the base station, or selecting the groups according to the physical response ofthe tags to a physical attribute of the signal sent from the base station to the tags, and communicating with the tags in each group. A single tag may be a member of one or more groups. Some groups may have no members. The most preferred embodiment of the invention is the method of selecting groups on the basis of the physical signal strength of the RF signal received from the tags by the base station. The tags have greater or less received signal

strength depending on the distance to the base station antenna, the relative orientation of the tag and the base station antennas, and the local conditions of reflectors and absorbers of radiation around the tag. The base station may also select groups of tags according to the polarization or the phase of the returned RF signal the RF carrier or Doppler shifted RF carrier or modulation frequency sent by the tags, or any another physical signal from the tags. The base station may also select groups of tags according to the physical response of the tags to the polarization, phase, carrier frequency, modulation frequency, or power ofthe RF signal sent by the base station. The communication protocol can be carried out simultaneously or sequentially with the selected groups. The physical characteristics used to group the tags can be measured simultaneously or sequentially. Different groups may be selected by taking the union, the intersection, or other combinations of the various groups of tags selected according to the different physical attributes. The tag group selection parameters may also include selecting groups by software, i.e. by selecting the groups according to information stored on the tag.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a generalized diagram of a base station communicating to one or more tags.

FIG. **2** is a diagram of a base station having two antennas for receiving information about the polarization of the signal sent by a tag.

FIG. **3** is a diagram of a base station having three antennas for receiving information about the polarization and phase position of the signal sent by a tag.

FIG. **4** is a diagram of a base station circuit which can select the strongest signals from signals sent by a plurality of tags.

FIG. **5** is a flow chart of the most preferred embodiment of the invention.

FIG. **6** is a flow chart of a preferred embodiment of the invention.

FIG. **7** is a flow chart of a preferred embodiment of the invention.

FIG. **8** is a flow chart of a preferred embodiment of the invention.

FIG. **9** is a flow chart of a preferred embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** sketches abase station **10** sending RF energy **21** and information to one or more tags **20**. The tags **20** may have varying distances from the base station, and the tag antennas **22** may be in any orientation with respect to the base station antenna. The base station comprises a transmitter section **100**, a computer section **50**, a circulator **170**, a receiver section **200**, and one or more antennas **185**.

FIG. **2** depicts a base station **10** which can group the tags **20** into groups on the basis of polarization of the RF radiation back scattered to the base station **10**. The base station **10** has two perpendicular antennas **185** and **185'** communicating with three tags **20**, **20'**, and **20"**. The antennas **185** and **185'**, and **22**, **22'** and **22"** are depicted as simple dipole antennas which transmit linearly polarized radiation with the polarization substantially parallel to the antennas. In the diagram shown, antenna **185** may communicate well with the tag **20** having an antenna **22** parallel to antenna **185**, less well with the antenna **22"** which is shown having a 45 degree orientation with respect to antenna **185**, and not at all with the tag with a perpendicular antenna **22'**. The groups are first selected on the basis of the response of the tags to the polarization of the signal sent out from the base station. In this example, two groups are selected: those tags which respond to the particular polarization, and those tags which do not respond. In the embodiment depicted in FIG. **2**, a signal sent out from antenna **185** brings responses from tag **20** and from tag **20"** to antenna **185**, and from tag **20"** alone to antenna **185'**. The tag antenna **22'** may not receive power from the perpendicular antenna **185**, and so tag **20'** remains silent. The tags are then further selected into subgroups according to the polarization of the returned signal. Thus, three groups of tags are selected by this method in this example, tag **20'** is in one group of "silent" tags, tag **20"** is in the group which is picked up by antenna **185'** because the polarization of the signal from tag **20"** can be detected by antenna **185'**, and tags **20** and **20"** are in the group with polarization components which may be picked up by antenna **185**. Communication with each of the two "non silent" groups in turn or in parallel simplifies and speed the communication protocol. In particular, the time taken to communicate with the first tag is markedly reduced. In the example given above, the signal returned to antenna **185'** is the signal from only a single tag **20"**, and that tag can return the tag identification number while the antenna **185** receives signal signifying more than one tag in the field. The tag **20"** may then be turned off for the duration of the communication procedure, and the process repeated to identify and shut down tag **20**. The sending antenna is then switched to antenna **185'**, and the remaining tag **20'** is identified. While a linear polarization scheme is shown as an example, it is clear to one skilled in the art that circularly polarized signals could also be used with good effect. The exact orientations of the antennas are also not critical to the invention, as long as there is a difference in the sensitivity of the antennas to the polarization of the RF signals sent by the tags. A single base station antenna could be used, as long as the polarization characteristics of the single base station antenna could be changed by the base station or by other means.

FIG. **3** shows a base station **10** with more than two dipole antennas **185**, **185'**, and **185"**. In this example, each antenna axis is mutually orthogonal so that the orientation of the linearly polarized backscattering from dipole antennas **22** in the field can be measured and the tags selected into groups for the communication procedure.

FIG. **4** shows a block diagram for circuitry which can allow the base station to select a group of tags by the signal strength received at the base station. The equipment for implementing the method of the most preferred embodiment of the invention uses five sections of the base station **10**: a computer section **50**, a transmitter section **100**; a receiver section **200**; a hybrid coupling device **170**; and an antenna **185**. The computer section may be a relatively unsophisticated circuit for controlling the transmitter and for receiving signals from the receiver, or it could include highly sophisticated workstations for interrogating and writing information to the tags. The transmitter section **100**, under control of the computer section **50**, sends a signal of the appropriate amplitude and frequency (which may or may not be modulated) to the hybrid **170**, which sends the (modulated) signal to the antenna **185**. The preferred modulation for communication to and from the tags is amplitude modulation, but it may be either frequency or phase modulation. The antenna **185** both sends out the RF carrier frequency which may or may not be modulated, and captures the signals radiated by the tags **20**. The antenna **185** captures

the signals radiated by the tags and sends the signals back to the hybrid **170**, which sends the signals to the receiver section **200**. The receiver section down converts and extracts the modulated signal from the carrier, and converts all the modulation energy it receives to a baseband information signal at its output. In the most preferred embodiment, the receiver has two outputs in quadrature called I (in phase with the transmitted carrier) and Q (quadrature, 90 degrees out of phase with the carrier). However, various embodiments of the invention have just one output. The hybrid element **170** connects the transmitter and receiver to an antenna while simultaneously isolating the transmitter and the receiver from each other. That is, the hybrid allows the antenna to send out a strong signal from the transmitter while simultaneously receiving a weak backscattered reflection. The strong transmitted signals being sent into the antenna must be eliminated from the receiver by the hybrid.

The transmitter section depicted by block **100** provides the energy and frequency signals for the transmitter carrier and the receiver down converter, and the amplified and modulated signal **160** which may be sent by the antenna **185**. The RF source **105** of signal **110** is usually isolated by an element **120** between the carrier signal source **105** and the rest of the circuit which avoids coupling problems of coupling reflections back to the RF source. The isolation element **120** is usually a circulator with one port terminated by a resistor. The isolated carrier signal **125** is split into two paths in a signal splitter element **130**. Most of the energy **140** goes to an amplifier modulator element **150**, while signal **135** takes a small signal to the receiver section depicted by block **200**. An optional phase and/or frequency shifter element **139** may be included between the signal splitter **130** and the receiver section **200** to provide control by the computer section **50** over line **157** of the reference phase and frequency signal **210** which the receiver section uses in detecting the signals from the tags. The phase and or frequency shifter **139** may send out signals differing by a small amount in frequency from the signal **110** sent out from the RF source **105**, or it may send out harmonics of the signal. In the amplifier modulator section **150**, the carrier frequency is amplified and modulated by a signal **155** controlled by computer section **50**. A preferred embodiment has a carrier frequency greater than 400 MHZ. A more preferred embodiment has a carrier frequency greater than 900 MHZ. The most preferred embodiment uses a carrier frequency offrom 2.3 to 2.5 Ghz, and this signal is amplitude modulated at 20–60 kHz. In the preferred embodiment, a direct modulation of the carrier frequency is depicted. However, an up converter of multiple frequencies may also be used. This modulated signal **160** enters the hybrid element **170** and is passed over lead **180** to the antenna **185**. Amodulator signal is applied at **155** into the modulator **150** to give a modulation which may be amplitude, frequency or phase modulation. The most preferred embodiment is amplitude modulation.

Inthe receiver section **200**, the received signal from the antenna **185** travels along lead **180** and enters the hybrid **170** which directs the signal along **220** to the receiver section depicted by block **200**. This signal comprises signals sent by the tags, which modulate the carrier frequency at a frequency of for example, 40 KHz, and the reflected unmodulated transmitter carrier signal reflected from the antennas or other reflectors in the field. The antenna will never be perfectly matched to the transmitter, and will reflect a signal which is about 20 dB down from the signal transmitted by the antenna. Of course, the carrier signals reflected by the tags, and the various reflections of the transmitted signal, will be much weaker than the signal transmitted from the antenna The receiver structure **230** of the most preferred embodiment here is a direct down conversion I and Q system where the mixing frequency signal **210** is generated by the source **105** and is the only send-out by the transmitter. The single down conversion system receiver removes the carrier frequency signal and generates two baseband signals which have frequencies in the 40 KHz region in quadrature **310** and **410**. These signals are filtered and amplified by means of signal processing in elements **300** and **400**. The signals **320** and **420** are passed to the computer section **50** for further processing.

The hybrid component **170** is typically a circulator. It passes signals from **160** to **180**, from A **180** to **220**, from **220** to **160** but not the other way around. Hence the transmitter is isolated from both the small amount of modulated carrier reflected by the antenna **185** (20 dB down typically) and the circulator (20 dB leakage typically) . The receiver is isolated from the large signal sent from the transmitter **100** to the antenna **185**, and receives about –20 dB signal from leakage from the circulator **170** and a further –20 dB of signal from the reflection from the antenna.

Of course, when the base station modulates the carrier signal to transfer information from the base station to the tags, the reflected modulated signals from the antenna and the leakage from the circulator will swamp out any signals sent by the tags. In the prior art, the tags communicate in a time period when there is no modulation of the carrier signal transmitted from the base station, or the tags communicate at a different carrier frequency than that transmitted by the base station, so that the receiver can pick out the modulated signals from the tags from all the reflections and leakages of the carrier signals. The present invention allows simple discrimination of signals by the tag to the base station sent as modulation of the base station carrier frequency, or as modulations of another frequency, from one or more tags, and allows the tags to be sorted in groups determined by the tag signal strength received at the base station.

The most preferred embodiment of the present invention is a method to sort the tags into groups by sending a steady, weak signal modulation at the communication modulation frequency to the tags in the time period where the prior art sends an unmodulated carrier signal so that the tags may communicate back to the base station. The steady, weak modulation frequency is not strong enough to influence the tag, but is strong enough so that the steady, weak modulated signals reflected from the antenna **185** and leaked around the hybrid **170** can be measured by the receiver and can be used to set a level for discriminating amongst the tag signals. In the most preferred embodiment, the communication to the tags is carried out by a 100% amplitude modulation of the carrier frequency at a 20–60 Khz frequency. The preferred protocol for the tags to detect such information is a 50 dB on/offratio, but this is not necessary to the invention. Any modulation of the carrier frequency which can conceivably be used for communication between the tags and the base station can be used. Such modulations as frequency modulation and phase modulation are well known in the art. In the present invention, a modulation amplitude less than that used to communicate with the tags is impressed on the outgoing carrier wave. The mismatch at the antenna will always cause that signal to be reflected and to be present at the receiver. This signal is detected at the receiver and is used to establish a deterministic signal floor. As backscattered modulated signals are received and are stronger than this coupling signal, the received back scattered signal dominates the receiver. Hence, a high sensitivity receiver

may be used with a forced coupled modulation from the transmitter as its signal noise floor, and behave in a predictable manner between the conditions of no tags in the field, a single tag in the field, multiple tags in the field, and interference. Furthermore, by varying the modulation strength of the weak, modulated signal, the returned signal strength of signals from the tags required to overcome the coupled modulator signal is increased or decreased thereby allowing the base station to select a group of tags based on the returned signal strength.

Fig.5 depicts a flow chart **500** of the most preferred method for selecting groups of tags and communicating with the tags in each group. A modulation frequency of 40 Khz is chosen as an example. At step **510**, the base station transmits a modulated signal to the base station antenna, and hence to the tags, instructing the tags to respond and return a modulated signal in a time period (time slot) defined by the tag communication protocol. At step **520**, the base station transmits a carrier wave to the base station antenna. The carrier wave has a steady 40 Khz amplitude modulation which is less than that required to communicate with the tags. The base station measures the 40 KHZ modulation received from the base station antenna in the time slot defined by the tag communication protocol. If the modulated signal received by the receiver **200** is steady in step **530**, the reflected modulated signal and leakage is greater than any signals received from tags, which would send an unsteady modulated signal. The base station then reduces the amplitude of the steady modulated signal in step **540** and the system returns to step **510**. If the modulated signal is not steady in step **530**, the base station checks at step **550** to see whether the modulated signal returned is steady outside the time slot defined by the tag communication protocol. If the modulated signal is unsteady when no tags are supposed to be sending signals, the unsteady signal is noise, and the receiver can not distinguish between signals sent by the tags and the noise. No tags are in reading position in the field, and the protocol is ended in step **560**. If however the modulated signal is steady outside the time slot, and unsteady in the time slot, one or more tags in the field are sending signals. These signals are stronger than the steady modulated signals received from the reflected steadily modulated carrier wave. If a single tag is in the field, and can be read at step **570**, the single tag is read and instructed to shut off, at step **590**, and the system is returned to step **540** to reduce the steady modulation and return to the beginning step **510** to try to find tags with less signal strength. If more than one tag is in the field and the tag signals interfere with each other so that they can not be read at step **570**, a multiple tag reading protocol is instituted in order to read the multiple tags at step **580**. The tags are read using the multiple tag reading protocol, and ordered to shut down, and the system is returned to step **540** to reduce the steady modulation and return to the beginning step **510** to try to find the group of tags with less signal strength than the first group.

Step **550** is preferably taken after step **530**, but step **550** may optionally be taken between steps **570** and **580** or after step **580** if no tags are read by the multiple tag reading procedure.

The most preferred embodiment of the invention uses a protocol in which the tags are commanded to return an identification signal in a particular time slot, but the same invention may be used where the tags are commanded to return information in any defined time periods.

While the preferred embodiment uses the naturally occurring reflections from the base station antenna **185** and leakage from the hybrid **170** to introduce the noise floor signal into the receiver **200**, many other means of introducing this signal to the receiver are possible to one skilled in the art. As an example, the steady 40 Khz modulation could be summed with the signals from the I/Q demodulator coming on lines **310** and **410**, or indeed a specially constructed device analogous to a two input I/Q demodulator could be constructed to accept the steady 40 Khz comparison signal from an outside source.

Additional embodiments of the invention include further subdividing the groups selected by the above method on the basis of the phase and/or polarization of the signals returned to the base station, as well as other physical or software group selection criteria.

A preferred embodiment of the invention is to select tags on the basis of the returned polrization of the signals. In the embodiment shown in FIG. **2**, groups of tags with antennas which return a linear polarization which is polarized more parallel to one or the other of the two dipole antennas **185** or **185'** sketched in FIG. **2** are selected. Returned signals from the two antennas are processed in parallel by two sets of receiver circuitry like that shown in FIG. **4**. The tags are interrogated by transmitting the modulated carrier signal from first one antenna **185**, then the other antenna **185'**, and four channels of signals (the I and Q channels received from each antenna) may be processed in parallel or in sequential fashion. This set up would select the tags into 8 groups, which of course may be further selected and grouped on the basis of the received signal strength or any other physical or software attribute.

FIG. **6** depicts a flow chart **600** of the preferred method of selecting groups of tags on the basis of the polarization of the signals returned to the base station. As an illustrative example, a base station comprising **2** antennas which are sensitive to different polarizations, such as depicted in FIG. **2**, is chosen. However, the number of antennas and whether the polarization is linear, circular, or some combination of the polariations may be chosen at will by one skilled in the art. Step **610** uses antenna **185** to send a signal to the tags instructing the tags to return a signal in the time slot determined by the communication protocol. The antenna **185** is then used to listen for signals from the tags inthe time slot where thetags return signals in step **620**. Signals returning from antenna **185** are analysed in step **630** to see if the base station can read the signal. If the signal is returned from a single tag, the base station communicates with the single tag in step **640**, and instructs the tag to shut itself down for the remainder of the communication protocol, or until it is specifically instructed to start returning signals again. The system is then returned to step **610** to look for more tags. If the signal returned by the tags to antenna **185** can not be read, either because there are no tags in the field in a position to be read by antenna **185** or because there multiple tags trying to communicate at the same time, the system may then try to read a single tag communicating to antenna **185'** in step **650**. If a single tag is successfully read, the system reads the tag at step **640**, shuts the tag down, and returns to the beginning step **610** to try to read again the tags which may be trying to communicate to antenna **185**. Since there is now one fewer tag in the field, a tag may now be read at step **630** on antenna **185**. If a single tag can not be read in step **650**, a multiple tag in the field reading procedure is instituted in step **660**. Steps **630** and **650** may be taken either sequentially or simultaneously, if two receivers are connected to the two antennas. If tags are read using one antenna in step **660**, the system decides in step **670** to communicate with the tags and turn them off and the system returns to step **610** to try to read a single or multiple tag from the other

antenna. If the multiple tag reading procedure does not read any tags from either antenna in step **660**, the system may switch transmitting antennas in step **680**, so that the commands and carrier wave are transmitted to antenna **185'** instead of antenna **185**. The method **600** of the invention can then be used to identify and select other groups not found in the first application of method **600**. Alternatively, the system may switch transmitting antennas between steps **650** and **660** to try to find, communicate with, and shut off single tags.

Another antenna perpendicular to the two antennas shown in FIG. **2**, which is placed remotely from the base station as shown in FIG. **3** allows all combinations of linear polarized backscatterring to be discriminated and allows the selecting of groups based on all polarizations of the received signal.

The three antennas **185**, **185'**, and **185"** shown in FIG. **3** allow many more groups to be selected on the basis of phase information. A possibly different group responds in the I and Q channels of the receiver of each antenna, and the groups may be different depending on which antenna or combination of antennas sends the carrier signal to the tags. Such group selection markedly cuts down the time needed to interrogate many tags in the field.

Base station antennas and tag antennas sensitive to circular and other polarizations are also known in the art, and these also may be used by one skilled in the art in an analogous way to that shown in FIGS. **1**, **2**, and **3** and described above.

An additional preferred embodiment of the invention is to use the information on the I and Q channels to select tags into groups on the basis of the phase of the returned signal which is dependent on the distance of the tags from the base station. As a tag is moved away from the base station, the carrier signal from the tag received at the base station changes from being in phase with the transmitted signal to being 90 degrees out of phase to being 180 degrees out of phase as the tag is moved one quarter of a wavelength of the RF EM field. The amplitude in the I channel and the Q channel changes accordingly, for example from a 1 in the I channel and a 0 in the Q channel, to a 0 in the I channel and a 1 in the Q channel, to a −1 in the I channel and 0 in the Q channel respectively. Thus, selecting the signals received from the tags on the I channel alone selects a group of tags for communication, while selecting the signals received from the tags on the Q channel selects a different group of tags which are at different distances from the base station antenna. Both the I and the Q channels may be used simultaneously or sequentially to communicate with the two different groups of tags. It is possible that some tags may be in both groups at the same time. As long as there are some tags in one group and not in the other, the selecting of the groups speeds up the tag communication protocol.

FIG. **7** gives a flow chart of a preferred method **700** of selecting groups of tags by the phase of the signal returned to the base station. A signal **710** is sent from the base station to the tags instructing the tags to return modulated signals to the base station in the time slot designated for tag response. In this time period, a steady carrier wave having a defined phase is transmitted **720** from the base station antenna. If a single tag can be read on the receiver I channel **730**, the tag is instructed to shut itself off in step **740** and the system returns to step **710**. If a single tag can not be read on the I channel in step **730**, the system tries to read a single tag in the Q channel in step **750**. If a single tag can be read step **750**, the tag is instructed to shut itself off in step **740**, and the system returns to the beginning **710** to try to pick up a single tag in the I channel. If single tags can not be read in either the I channel or the Q channel, the system decides in step **750** to institute the multiple tag in field reading procedure **760**. If tags are identified in either I or Q channels in step **760**, the system may shut the identified tags off and return to step **710** to try to find single tags grouped in the other channel.

While the above method **700** has steps **730** and **750** proceeding sequentially, it is well within the scope of the invention that steps **730** and **750** may also be carried out simultaneously. If a single tag is read on either the I channel or the Q channel, the system returns to step **710**. If no single tags are read on steps **730** and **750**, the system proceeds to step **760**. In step **760**, if tags are identified and shut off, the system may at any time return to step **710** to carry out the simpler subgrouping.

With the addition of an optional phase shifting element **139**, signals from a particular tag are brought entirely into the I channel or the Q channel. The tags may then be sorted into many more groups than the two groups defined by the I and Q channels as explained above. If only one channel of information, for example the I channel, is used, changing the phase shifting element **139** to give a series of different phase delays may sort the tags into more groups. The computer section **50** may end the phase shift element **135** instructions over line **157** to shift phase by, for example 0, 30, 60, and 90 degrees which would select four different groups of tags for communication. Using both the I and Q channels, and 3 phase shifts of 0, 30, and 60 degrees gives 6 groups as another example.

If the carrier signal frequency sent out from the base station is changed, a particular tag will be a different number of quarter wavelengths from the base station and the signal will be distributed in a different way between the I and Q channels of the base station receiver. A preferred embodiment of the present invention is to select different groups of tags according to the response of the tag to such a frequency shift of the base station. FIG. **8** gives a flow chart for the method **800** of selecting groups of tags on the basis of the response of the tag to the frequency of the carrier signal sent out from the base station. In step **810**, the base station sends out a carrier wave having a first frequency f_1. In step **820**, the base station instructs the tags to return signals. The signal returning to the base station is analyzed in a single channel of the receiver in step **830**. If the signal can be read, the tag is communicated with and turned off in step **840** and the system returns to step **820** to find single tags which may have less received signal strength than the tag found in the previous cycle. If no tag is found in step **830**, the system then changes the carrier frequency sent out from the base station in step **850** to a frequency f_2, and then sends signals to the tags to return signals in step **860**. If single tag can be read in step **870**, the tag is communicated with and shut off in step **880**, and the system returned to step **860**. If no tags are found in step **870**, the system checks to see if any tags have been found in previous cycles through step **870**, and if so the system is returned to the beginning step **810** to search the first frequency again. If no tags have been found in previous cycles, the system goes to the multiple tag in the field search procedure **890**. While two frequencies are used in this example, the method is not limited to the use ofjust two frequencies, and many more could be used. Use of any plurality of frequencies which shift the relative phase of the returned signal is contemplated by the inventors.

A further embodiment of the invention is to select the tags into groups on the basis of the frequency response of the tags. Tags responsive to different carrier frequencies are

interrogated, and the base station is programmed to shift from one frequency to the next to select and interrogate these different groups of tags in a sequential fashion. Tags may be grouped into tags which respond to 900 MHZ, and tags which respond to 2.4 MHZ, as an example.

A further embodiment of the invention is to select the tags into groups on the basis of the response of the tags to the RF power transmitted from the base station. The method of the embodiment is to send a low power to the set of tags, and communicate with the set of tags which respond to the low power, then turn the tags which responded to the low power off. Next, the RF power transmitted from the base station is raised, and tags in a group which are further away than the first group respond, and are in turn communicated with and turned off The process may be repeated until all tags in communication range of the base station with the maximum power allowed have finished the communication protocol.

Tags which themselves return different carrier frequencies than the base station carrier frequency are known in the art. A further embodiment of the invention is to select groups of such tags on the basis of the different measured carrier frequencies. The base station is programmed to receive the different tag carrier frequencies, either simultaneously or sequentially and to interrogate each group of tags. The different carrier frequencies known in the art are often the harmonics of the base station carrier frequency. However, the invention is not limited to the particular carrier frequency returned by the tags to the base station. If the tags can be selected into at least two groups, the communication protocol is speeded up.

FIG. **9** is a flow chart of a method of grouping the tags on the basis of the carrier frequency of the tags. The receiver is set to receive a carrier signal of frequency f, in step **910**. Step **920** instructs the tags to return signals. If a single tag is read in step **930**, the system instructs the tag in step **940** to turn off and return to step **920**. If no tag can be read in step **930**, the receiver frequency is changed in step **950** to f_2, and the tags are instructed in step **960** to return signals. If a single tag can be read in step **970**, the tag is communicated with and shut off in step **980**. If a single tag can not be read in step **970**, the multiple tag reading protocol is instituted. While two frequencies are used in this example, many more frequencies could also be used.

The carrier frequencies emitted by the tags and received by the base station may be apparently shifted from the base station carrier frequency by the Doppler shift due to the relative motion of the tags and the base station. A further embodiment of the invention is to select groups of tags according to the Doppler shift of the carrier frequency sent by the tags and received by the base station. As an example, two groups of tags, those with relative motion of the tags towards the base station, and those with relative motion away from the base station, are selected for the communication protocol. This group selection is particularly valuable for a base station communicating with tags on one side of a doorway, for example, to measure whether the tags are carried into or out of a room.

Tags may return different modulation frequencies. A further embodiment of the invention is to select groups oftags on the basis of the modulation frequency of the returned tag signal. The base station is programmed to interrogate each group of tags either simultaneously or sequentially.

The invention is not limited to the above examples. The selection of groups of tags from a set of tags on the basis of any physically measured characteristics or attributes of the returned signal from the tags in response to any physical characteristic or attribute of the signal sent from the base station is well within the scope of the invention, as is the combination of the selection of groups on the basis of both physically measured characteristics and information contained on the tags.

We claim:

1. A method for communicating between a base station and a set of radio frequency (RF) transponders (tags), comprising;

selecting a plurality of groups of tags from the set of RF tags, the selection according to a physical attribute of the response of the tags to a first RF signal sent from the base station; and

communicating with tags in each group.

2. The method of claim **1**, wherein the communication with tags in each group is simultaneous.

3. The method of claim **1**, wherein the physical response of the tags is a polarization of a second RF signal returned by the tags, the second RF signal received by the base station.

4. The method of claim **3**, wherein the communication with tags in each group is simultaneous.

5. The method of claim **3**, wherein the selection of groups of tags is by signals received by at least two antennas of the base station.

6. The method of claim **1**, wherein the physical response of the tags is a phase of a second RF signal returned by the tags, the second RF signal received by the base station.

7. The method of claim **6**, wherein the communication with tags in each group is simultaneous.

8. The method of claim **6**, wherein the phase the signals received from a first group of tags is primarily in phase with a carrier signal sent out from the base station, and the phase of the signals received from a second group of tags is primarily 90 degrees out of phase with the signal sent out from the base station.

9. The method of claim **1**, wherein the physical response of the tags is a frequency of a second RF signal returned by the tags, the second RF signal received by the base station.

10. The method of claim **9**, wherein the communication with tags in each group is simultaneous.

11. The method of claim **9**, wherein the frequency of the second RF signal received from the tags by the base station is harmonically related to a base station carrier frequency.

12. The method of claim **9**, wherein the frequency of the second Rf signal received from the tags by the base station is a base station carrier frequency Doppler shifted by relative motion between the tags and the base station.

13. The method of claim **12**, wherein a first group of tags is a group of tags having relative motion towards the base station, and a second group of tags is a group of tags having relative motion away from the base station.

14. The method of claim **1**, wherein the physical response of the tags is a modulation frequency of a second RF signal returned by the tags, the second RF signal received by the base station.

15. The method of claim **14**, wherein the communication with tags in each group is sequential.

16. The method of claim **1**, wherein the physical response of the tags is a signal strength of a second RF signal returned by the tags, the second RF signal received by the base station.

17. The method of claim **16**, wherein the communication with tags in each group is sequential.

18. The method of claim **17**, wherein the selection of a first group of tags is followed in order by communication with the first group of tags, the selection of a second group of tags, and communication with the second group of tags.

19. The method of claim 18, wherein the signal strength of the second RF signal received from the tags by a receiver of the base station is compared to a signal strength of a third signal introduced by the base station into the receiver of the base station, and wherein the first group of tags is selected to be the group of tags which have signal strengths greater than the signal strength of the third signal.

20. The method of claim 1, wherein the physical response of the tags is a polarization and a phase of a second RF signal returned by the tags, the second RF signal received by the base station.

21. The method of claim 1, wherein the physical response of the tags is a polarization and a signal strength of a second RF signal returned by the tags, the second RF signal received by the base station.

22. The method of claim 1, wherein the physical response of the tags is a phase and a signal strength of a second RF signal returned by the tags, the second RF signal received by the base station.

23. The method of claim 1, wherein the physical response ofthe tags is a polarization and a phase and a signal strength of a second RF signal returned by the tags, the second RF signal received by the base station.

24. A method for communicating between a base station and a set of radio frequency (RF) transponders (tags), comprising;

selecting a plurality of groups oftags from the set of RF tags, the selection according to a physical attribute of the response of the tags to a polarization of a first RF signal sent from the base station; and

communicating with the tags in each group.

25. A method for communication between a base station and a set of RF tags, comprising;

I) transmitting a carrier wave with a first modulated signal to a base station antenna, the first modulated signal instructing the set of tags to return a second modulated signal in a time period (slot) defined by a tag communication protocol; then

II) transmitting a carrier wave with a steady amplitude modulation to the base station antenna, the steady amplitude modulation being less than an amplitude modulation required to communicate with the set of tags; and

III) measuring a modulation of a carrier wave received from the base station antenna.

A) when the modulation of the carrier wave received from the base station antenna is steady, reducing the amplitude of the modulation of the carrier wave with a steady amplitude modulation and returning to step I);

B) when the modulation of the carrier wave received from the base station antenna is not steady, and

a) when the modulation can be read, communicating with a first tag and then instructing the first tag to cease sending modulated signals, then reducing the amplitude of the modulation of the carrier wave with a steady amplitude modulation and returning to step I);

b) when the modulation can not be read, and

i.) when the modulation of the carrier wave received from the base station antenna outside the communication protocol time slot is steady, communicating with multiple tags using a multiple tag communication protocol, then instructing the multiple tags to cease returning the second modulated signal,reducing the amplitude of the modulation of the carrier wave with a steady amplitude modulation and returning to step I);

ii.) when the modulation of the carrier wave received from the base station antenna outside the communication protocol time slot is not steady, stopping.

26. A method for communication between a base station and a set of RF tags, comprising;

a) transmitting a first modulated signal to a base station antenna, the first modulated signal instructing the set of tags to return a second modulated signal in a time period (slot) defined by a tag communication protocol; then

b) transmitting an unmodulated first carrier wave having a defined first phase to the base station antenna during the time slot defined by a tag communication protocol; then

c) measuring a second modulated signal of a second carrier wave returned by the tags to the base station antenna in the time slot defined by the tag communication protocol, the second carrier wave having a second defined phase with respect to the first phase of the first carrier wave, and communicating with a first group of tags producing the modulated second carrier wave; and

d) measuring a third modulated signal of a third carrier wave returned by the tags to the base station antenna in the time slot defined by the tag communication protocol, the third carrier wave having a third defined phase with respect to the first phase of the first carrier wave, and communicating with a second group of tags producing the modulated third carrier wave.

27. The method of claim 26, wherein steps c) and d) are carried out simultaneously.

28. The method of claim 26, wherein steps c) and d) are carried out sequentially.

* * * * *

EXHIBIT C

US005828318A

United States Patent [19]

Cesar

[11] Patent Number: 5,828,318

[45] Date of Patent: Oct. 27, 1998

[54] **SYSTEM AND METHOD FOR SELECTING A SUBSET OF AUTONOMOUS AND INDEPENDENT SLAVE ENTITIES**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **646,539**

[22] Filed: **May 8, 1996**

[51] **Int. Cl.**[6] **G08C 19/00**; G05B 23/02

[52] **U.S. Cl.** **340/825.69**; 340/825.06; 340/825.07; 340/825.08; 395/290; 395/291; 395/683

[58] **Field of Search** 340/895.69, 825.06, 340/825.07, 825.08, 825.12, 825.71, 571, 572; 395/290, 201, 683

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Primary Examiner—Michael Horabik

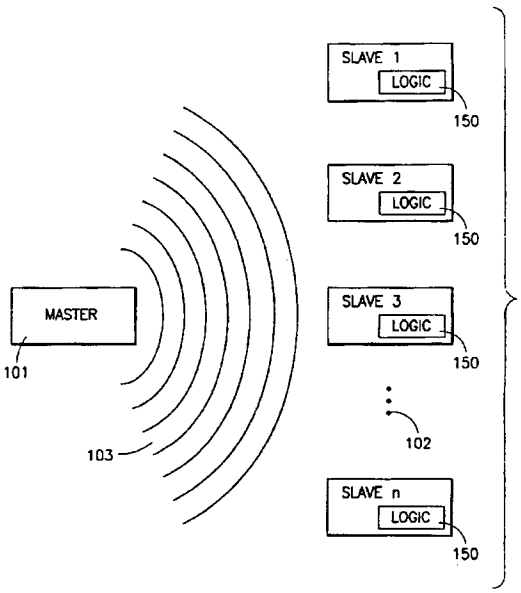
Assistant Examiner—Anthony A. Asongwed

Attorney, Agent, or Firm—Louis J. Percello; Ronald L. Drumheller

[57] **ABSTRACT**

A master entity is capable of broadcasting commands to a plurality of three-state-selection machine slaves. Transitions from one state to another are effected on instruction from commands in a sequence of commands broadcast from the master. Slaves move to another state when they satisfy a primitive condition specified in the command. By moving slaves among the three sets, a desired subset of slaves can be isolated in one of the sets. This desired subset of slaves then can be moved to one of the states that is unaffected by commands that cause the selection of other desirable subsets of slaves.

18 Claims, 35 Drawing Sheets



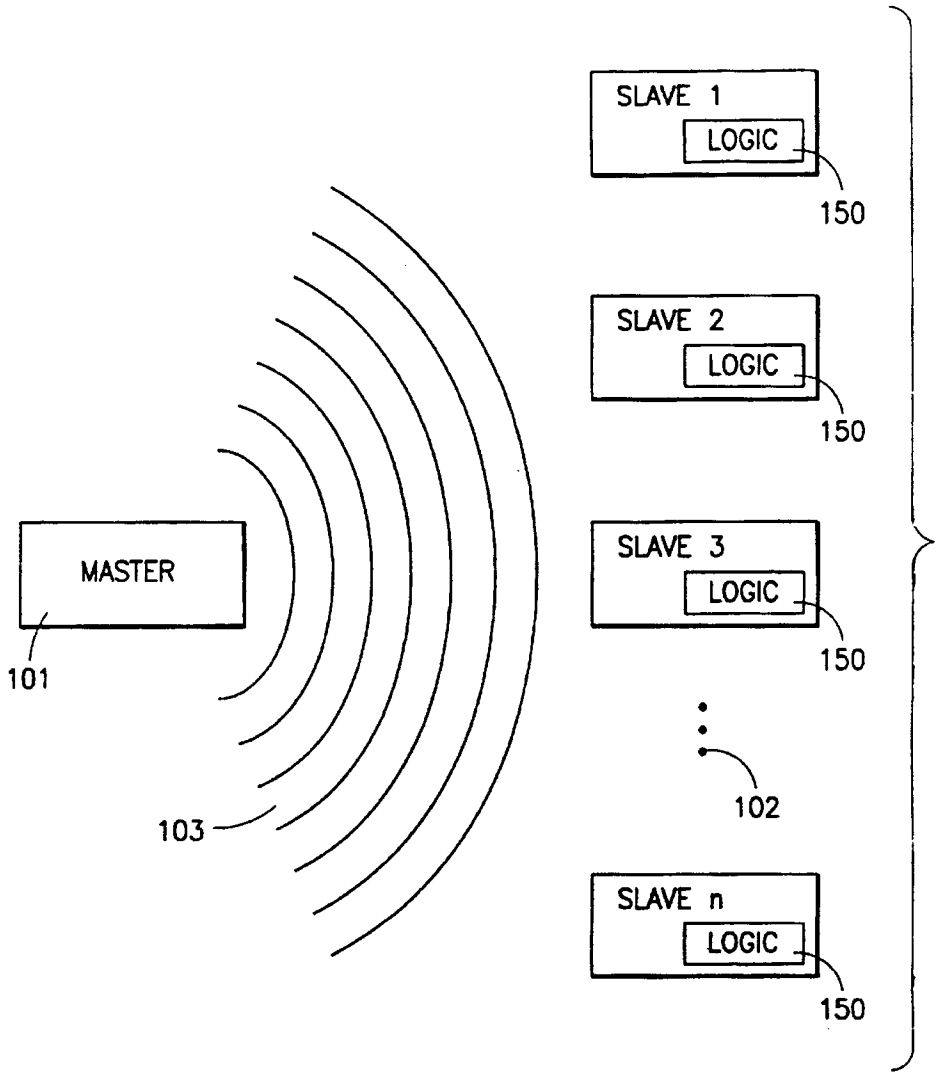

SLAVE 1
LOGIC
150
SLAVE 2
LOGIC
150
SLAVE 3
LOGIC
150
102
SLAVE n
LOGIC
150
MASTER
101
103

FIG. 1

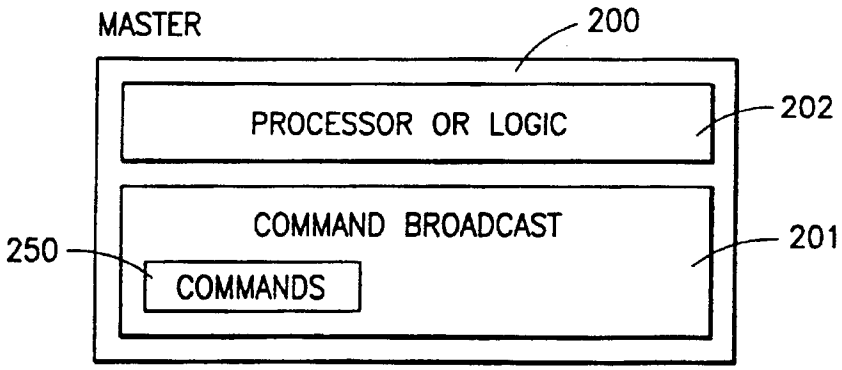

MASTER
200
PROCESSOR OR LOGIC
202
COMMAND BROADCAST
250
COMMANDS
201

FIG. 2

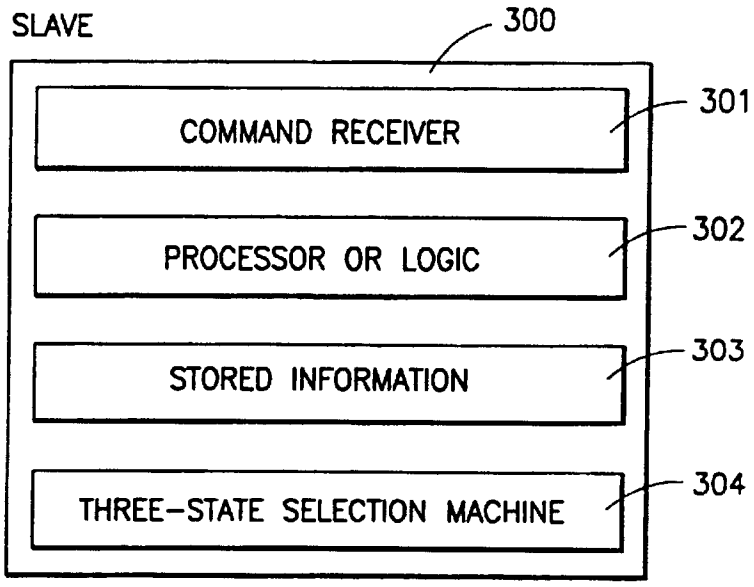

SLAVE
300
COMMAND RECEIVER
301
PROCESSOR OR LOGIC
302
STORED INFORMATION
303
THREE-STATE SELECTION MACHINE
304

FIG. 3

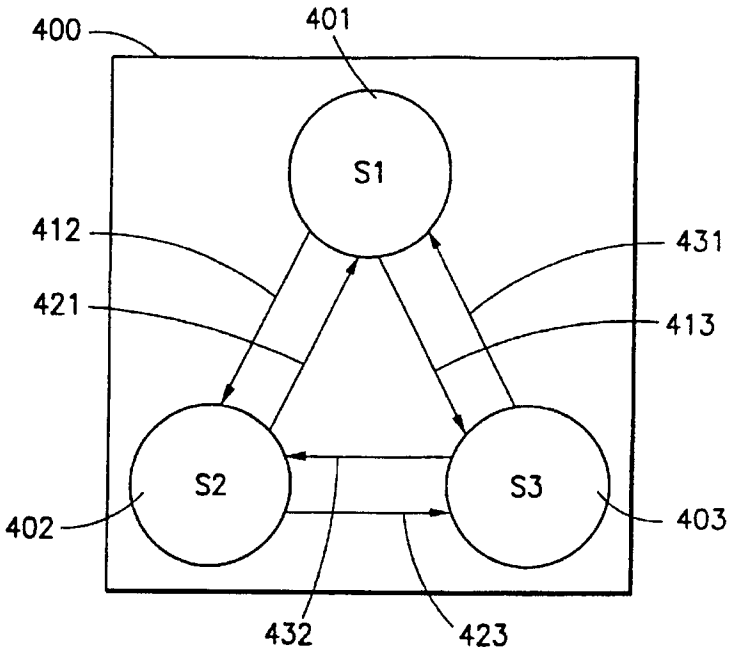

400
401
S1
412
431
421
413
S2
S3
402
403
432
423

FIG. 4

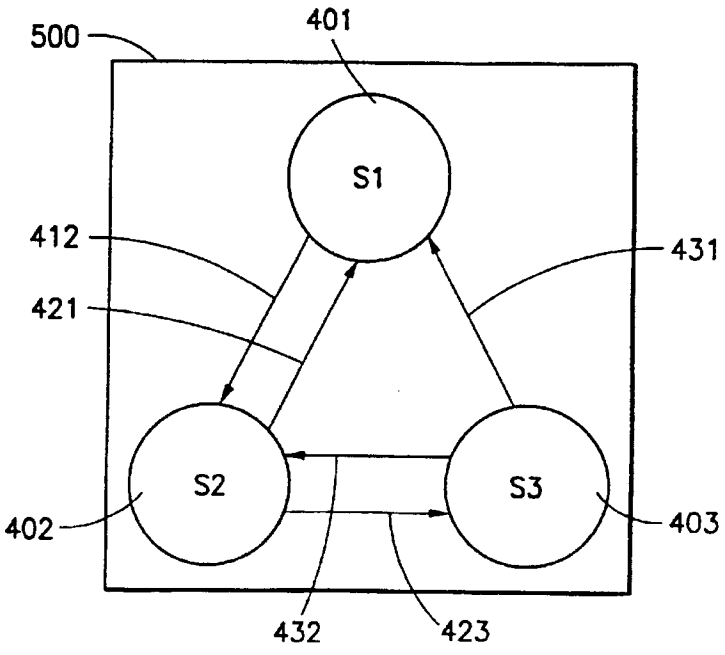

500
401
S1
412
431
421
S2
S3
402
403
432
423

FIG. 5

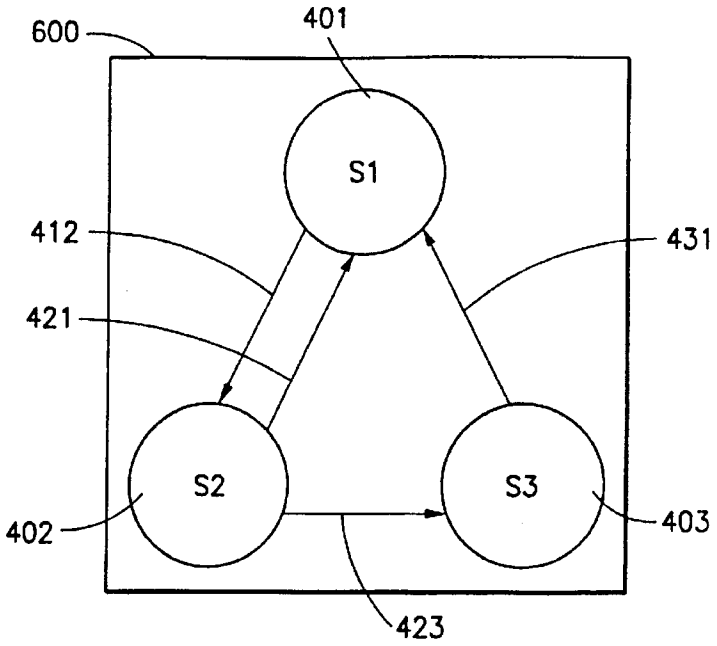

600
401
S1
412
431
421
S2
S3
402
403
423

FIG. 6

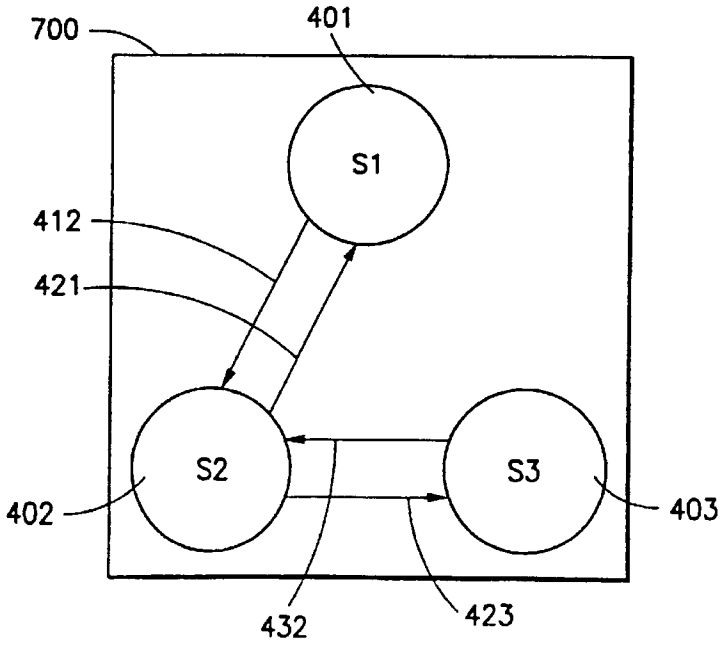

700
401
S1
412
421
S2
S3
402
403
432
423

FIG. 7

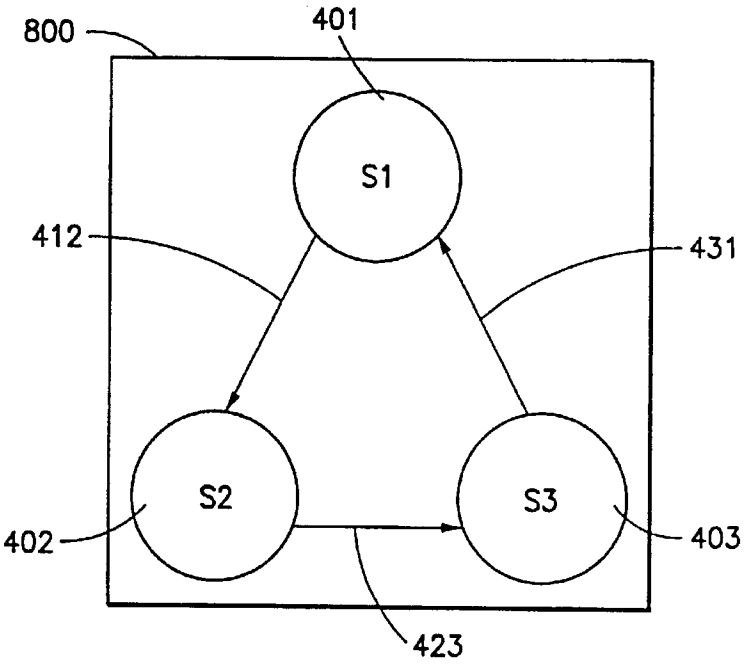

800
401
S1
412
431
S2
S3
402
403
423

FIG. 8

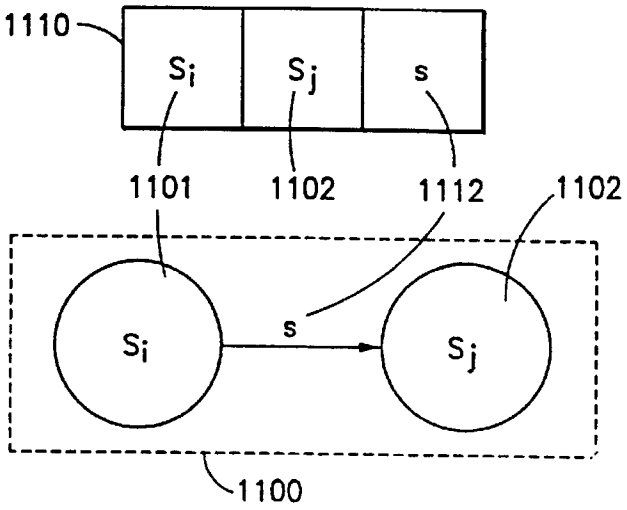

1110
S_i
S_j
s
1101
1102
1112
1102
S_i
s
S_j
1100

FIG. 11

	T12	T21	T23	T32	T31	T13
900	YES	YES	YES	YES	YES	YES
901	YES	YES	YES	YES	YES	NO
902	YES	YES	YES	YES	NO	YES
903	YES	YES	YES	NO	YES	YES
904	YES	YES	NO	YES	YES	YES
905	YES	NO	YES	YES	YES	YES
906	NO	YES	YES	YES	YES	YES
907	YES	YES	YES	NO	YES	NO
908	YES	YES	NO	YES	NO	YES
909	YES	NO	YES	YES	YES	NO
910	NO	YES	YES	YES	NO	YES
911	YES	NO	YES	NO	YES	YES
912	NO	YES	NO	YES	YES	YES
913	YES	YES	YES	YES	NO	NO
914	YES	YES	NO	NO	YES	YES
915	NO	NO	YES	YES	YES	YES
916	YES	NO	YES	NO	YES	NO
917	NO	YES	NO	YES	NO	YES

FIG. 9

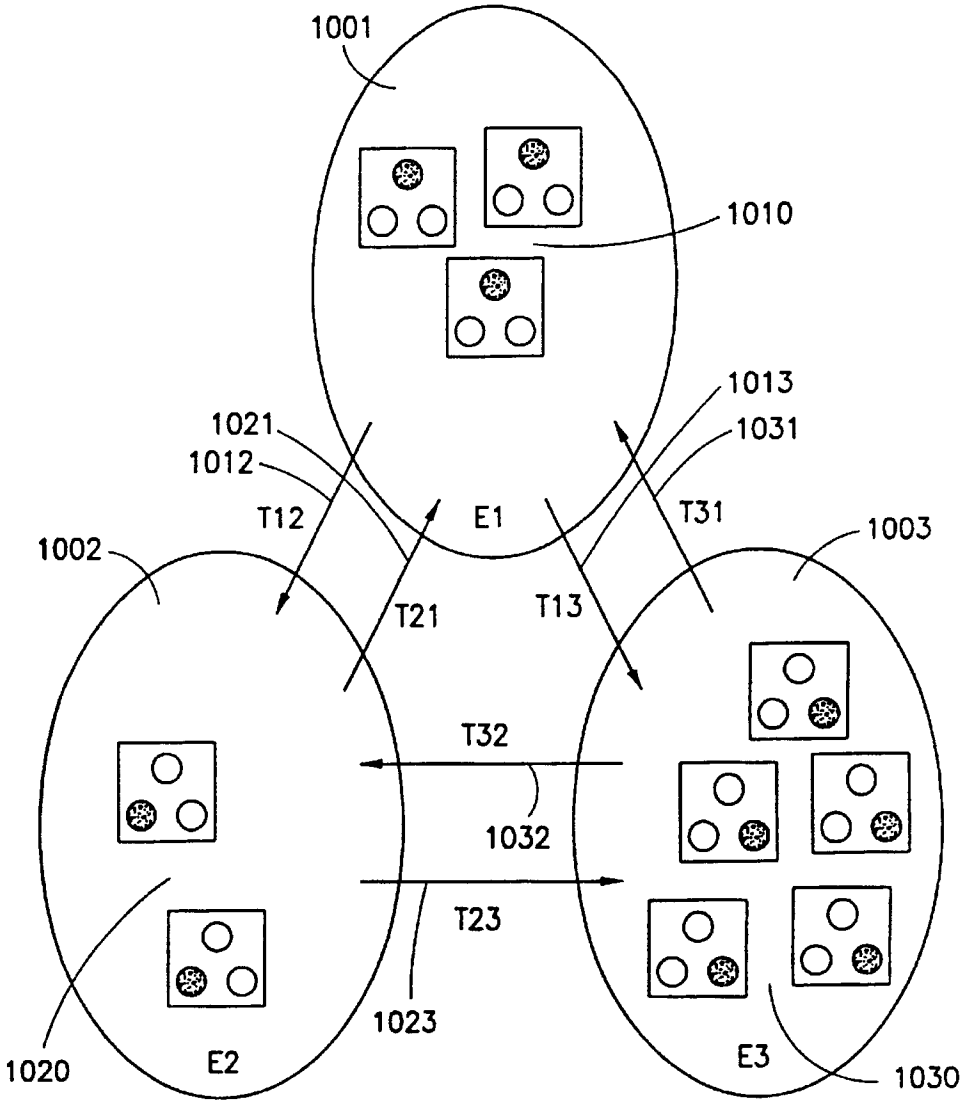

1001
1010
1013
1031
1021
1012
T12
E1
T31
1003
1002
T21
T13
T32
1032
T23
1023
E2
E3
1020
1030

FIG. 10

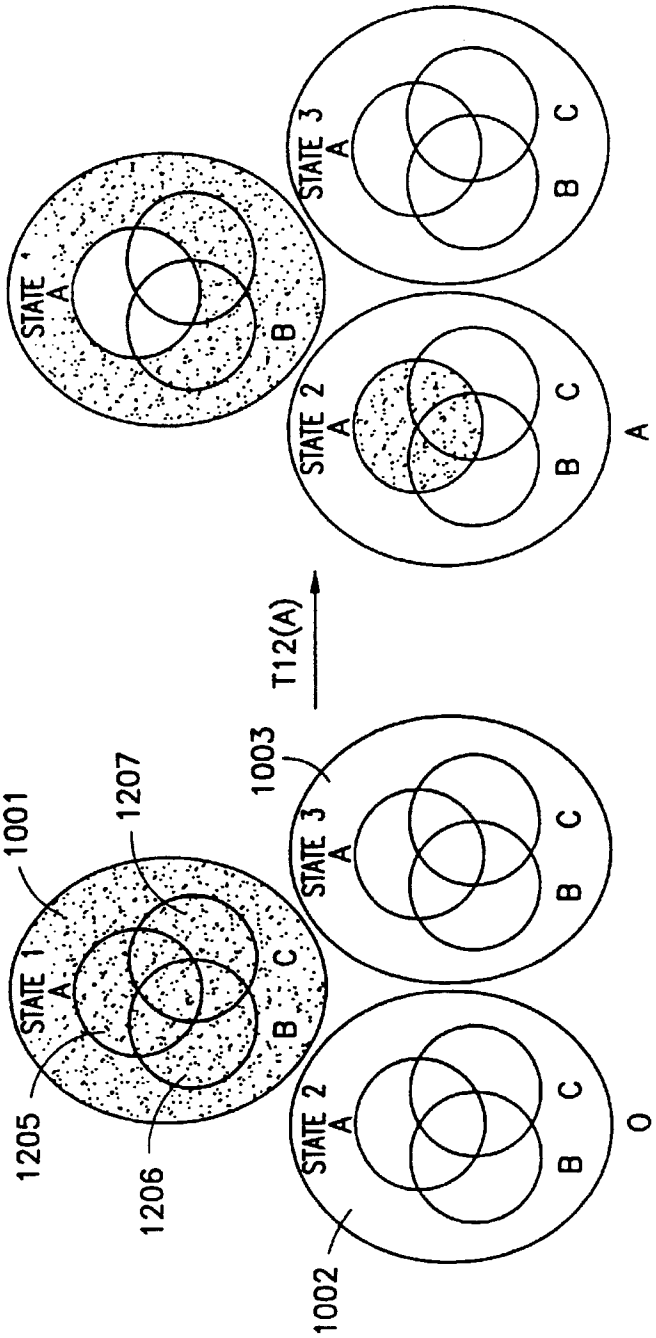

STATE 1
A
B
C
1001
1207
1205
1206
1003
T12(A)
STATE 3
STATE 2
1002
STATE 2
STATE 3
STATE 1
A
B
C
A
B
C
A
B
C
A
B
C
A
B
C
A
B
C
O

FIG. 12

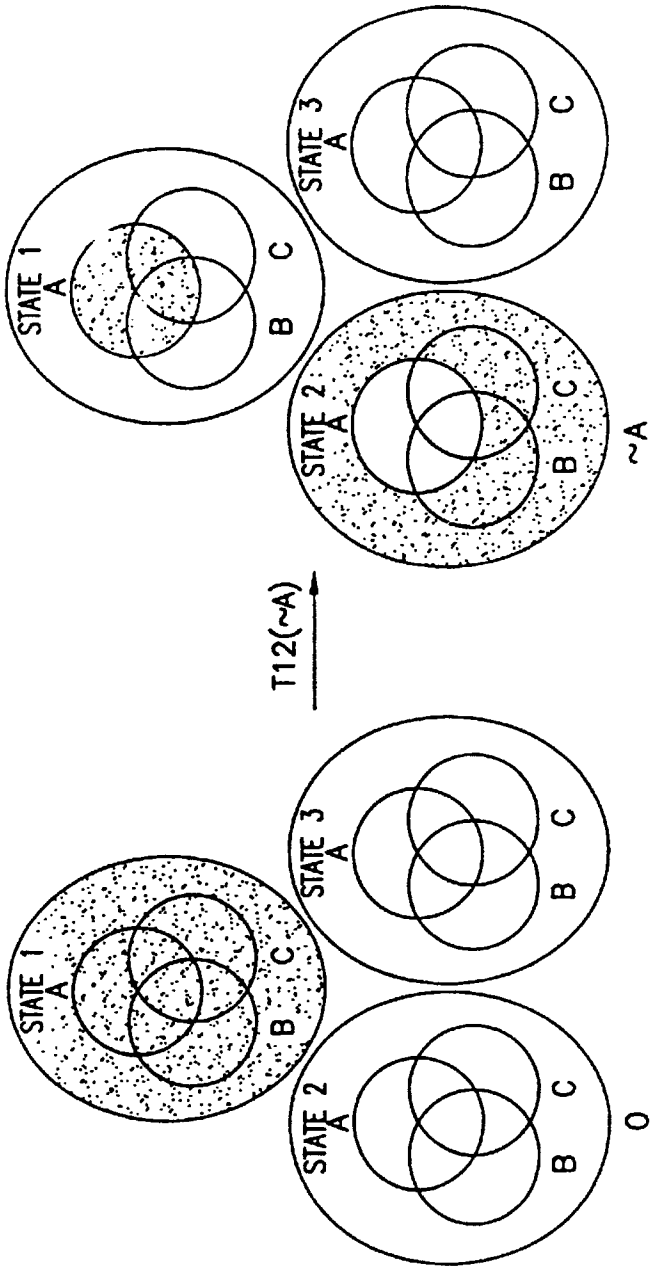

STATE 1
A
B
C
STATE 3
A
B
C
STATE 2
A
B
C
~A
T12(~A)
STATE 1
A
B
C
STATE 3
A
B
C
STATE 2
A
B
C
0

FIG. 13

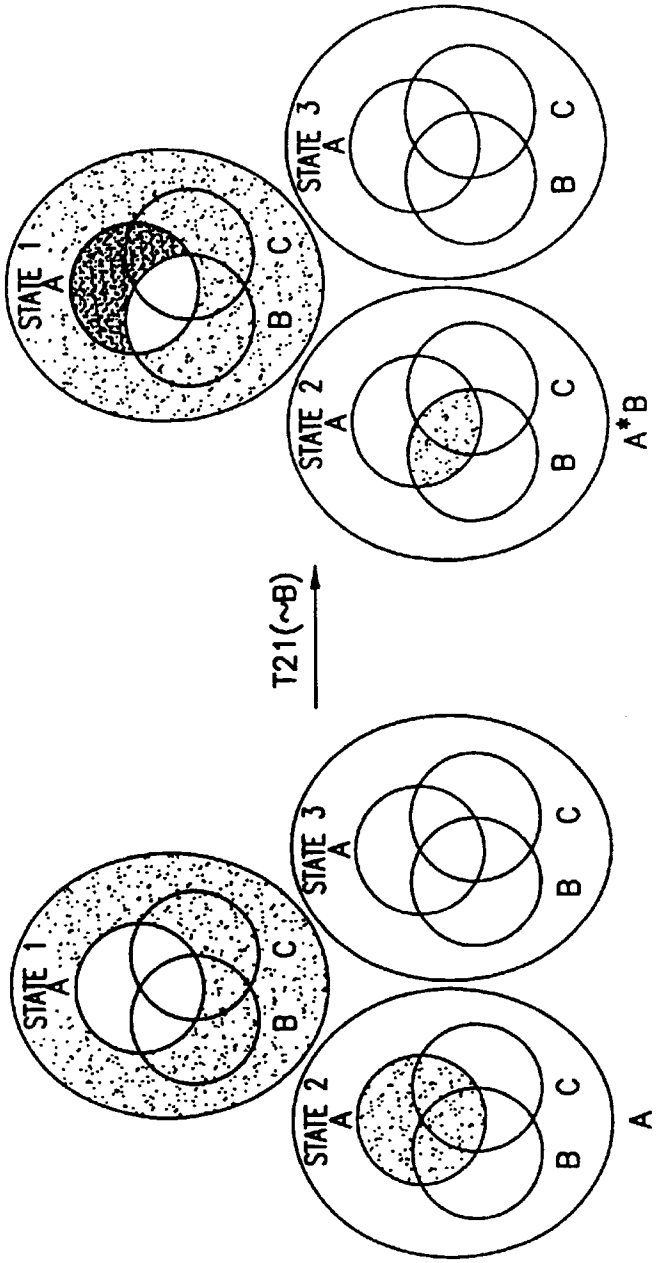

STATE 1
A
B
C
STATE 2
A
B
C
A*B
STATE 3
A
B
C
T21(~B)
STATE 1
A
B
C
STATE 2
A
B
C
A
STATE 3
A
B
C

FIG. 14

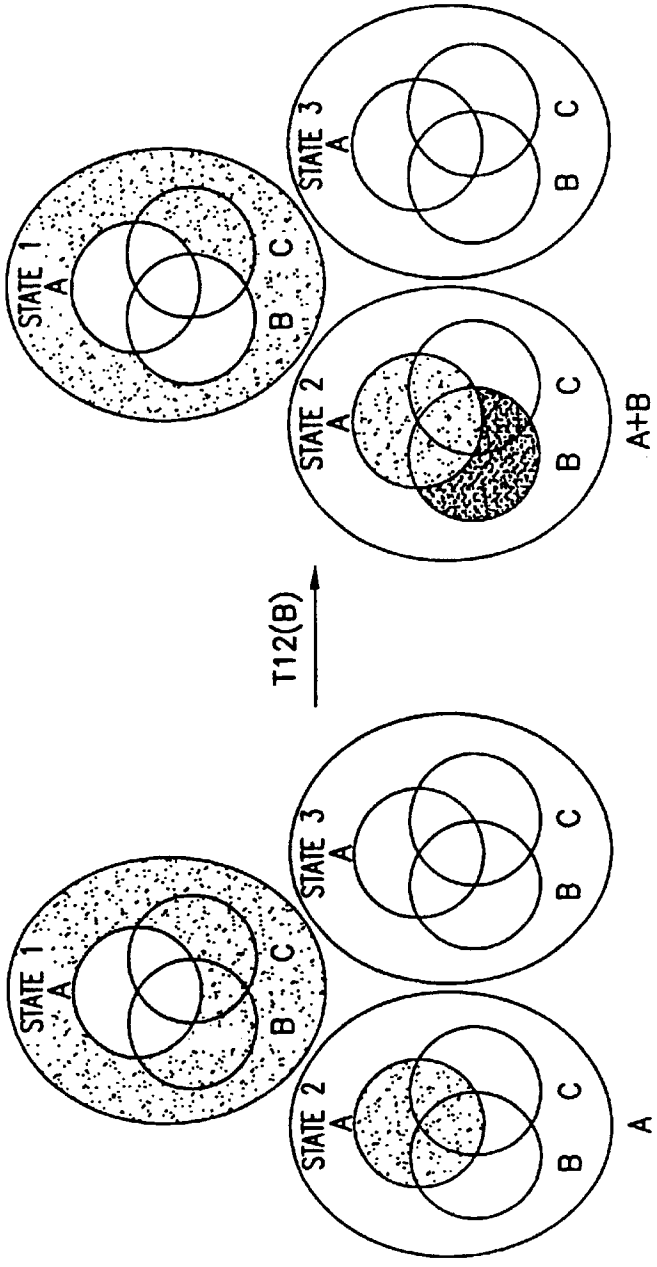

STATE 1
A
B
C
STATE 3
A
B
C
STATE 2
A
B
C
A+B
T12(B)
STATE 1
A
B
C
STATE 3
A
B
C
STATE 2
A
B
C
A

FIG. 15

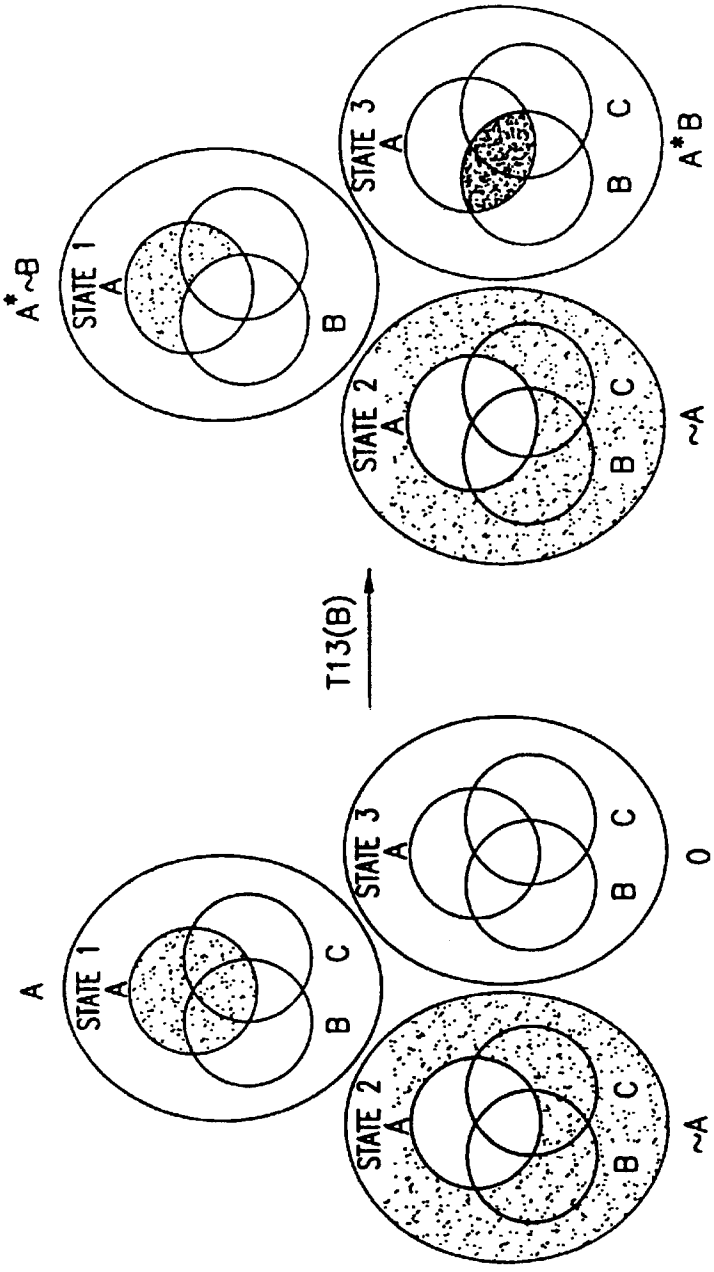

A*~B
STATE 1
A
B
STATE 3
A
B C
A*B
STATE 2
A
B C
~A
T13(B)
A
STATE 1
A
B C
STATE 3
A
B C
0
STATE 2
A
B C
~A

FIG. 16

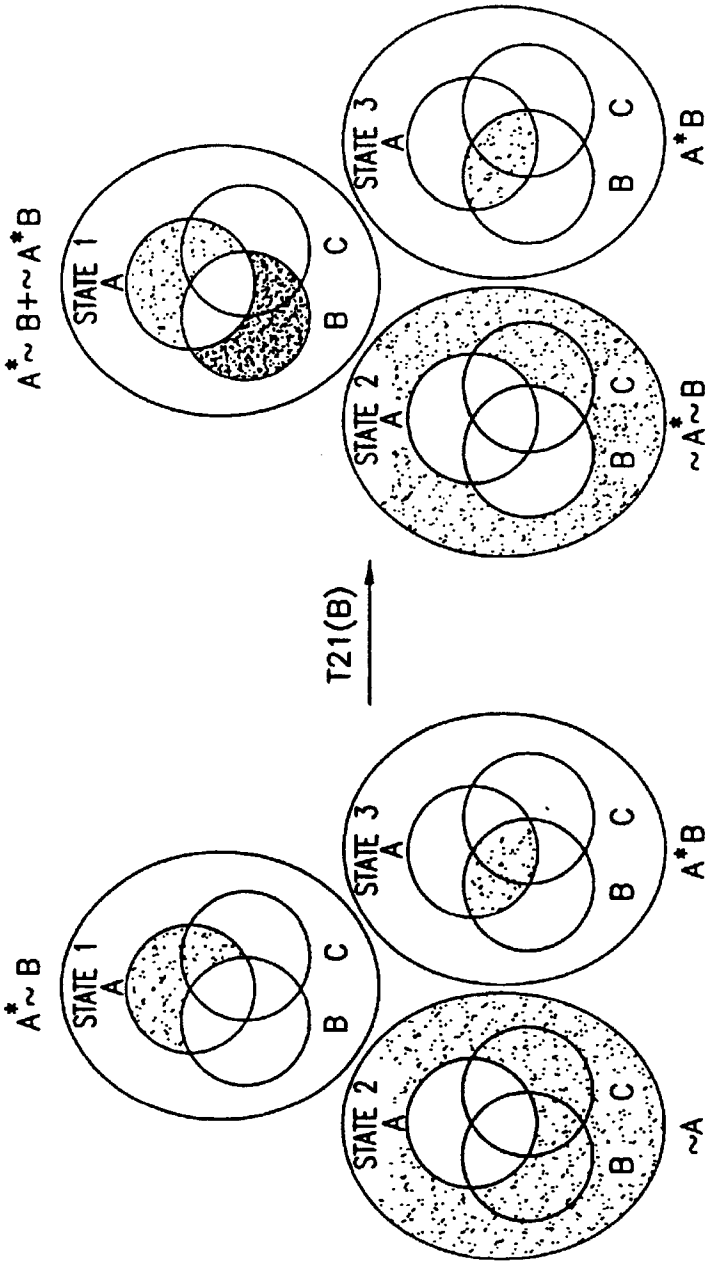

A*~ B+~ A*B
STATE 1
A
B C
STATE 3
A
B C
A*B
STATE 2
A
B C
~A*~B
T21(B)
A*~ B
STATE 1
A
B C
STATE 3
A
B C
A*B
STATE 2
A
B C
~A

FIG. 17

1810	STATE 1	STATE 2	STATE 3
1800	1	0	0
1801 T12(~A)	A	~A	0
1802 T13(B)	A*~B	~A	A*B
1803 T21(B)	A*~B+~A*B	~A*~B	A*B

FIG. 18

1910	STATE 1	STATE 2	STATE 3
1900	1	0	0
1901 T12(A)	~A	A	0
1902 T23(B)	~A	A*~B	A*B
1903 T12(B)	~A*~B	A*~B+~A*B	A*B

FIG. 19

2010	STATE 1	STATE 2	STATE 3
2000	1	0	0
2001 T13(A)	~A	0	A
2002 T32(B)	~A	A*B	A*~B
2003 T13(B)	~A*~B	A*B	A*~B+~A*B

FIG. 20

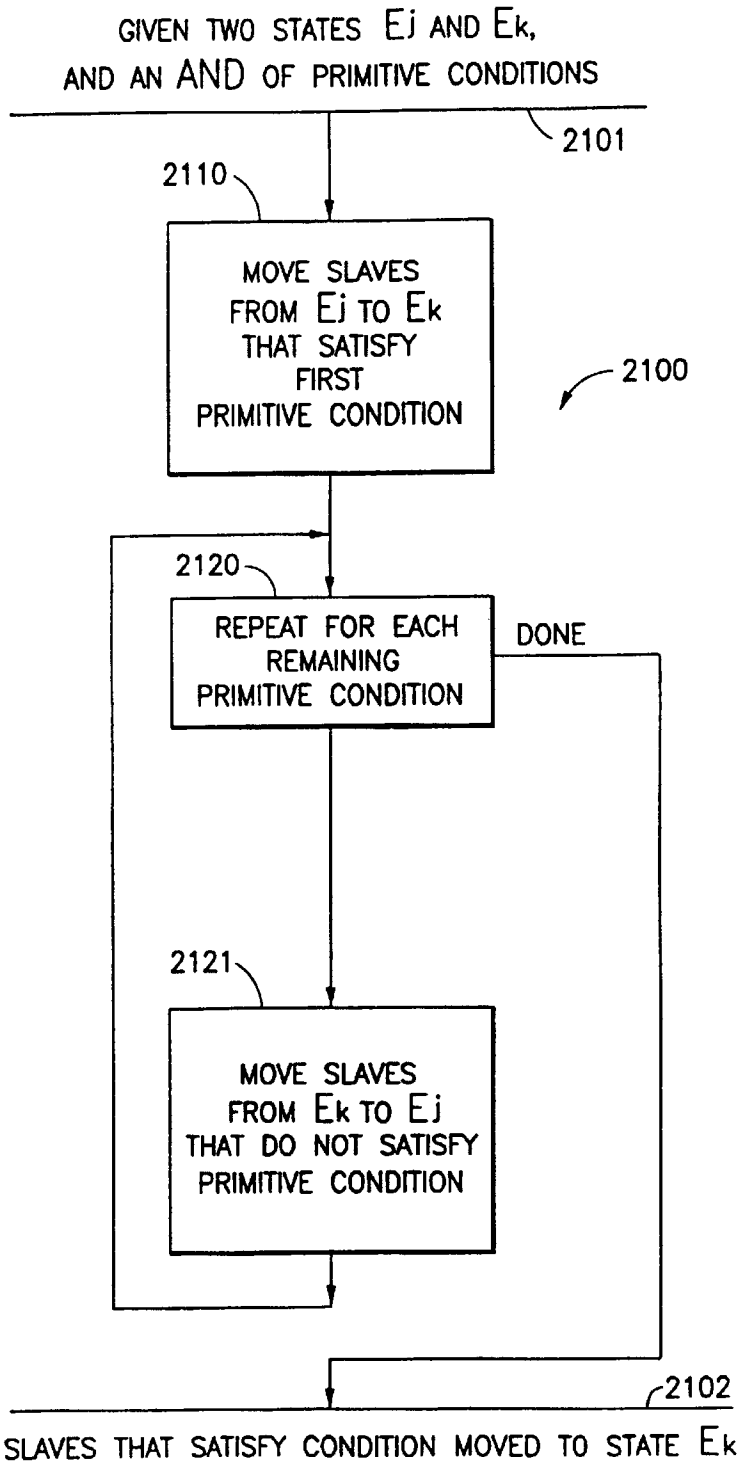

GIVEN TWO STATES Ej AND Ek,
AND AN AND OF PRIMITIVE CONDITIONS
2101
2110
MOVE SLAVES FROM Ej TO Ek THAT SATISFY FIRST PRIMITIVE CONDITION
2100
2120
REPEAT FOR EACH REMAINING PRIMITIVE CONDITION
DONE
2121
MOVE SLAVES FROM Ek TO Ej THAT DO NOT SATISFY PRIMITIVE CONDITION
2102
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 21

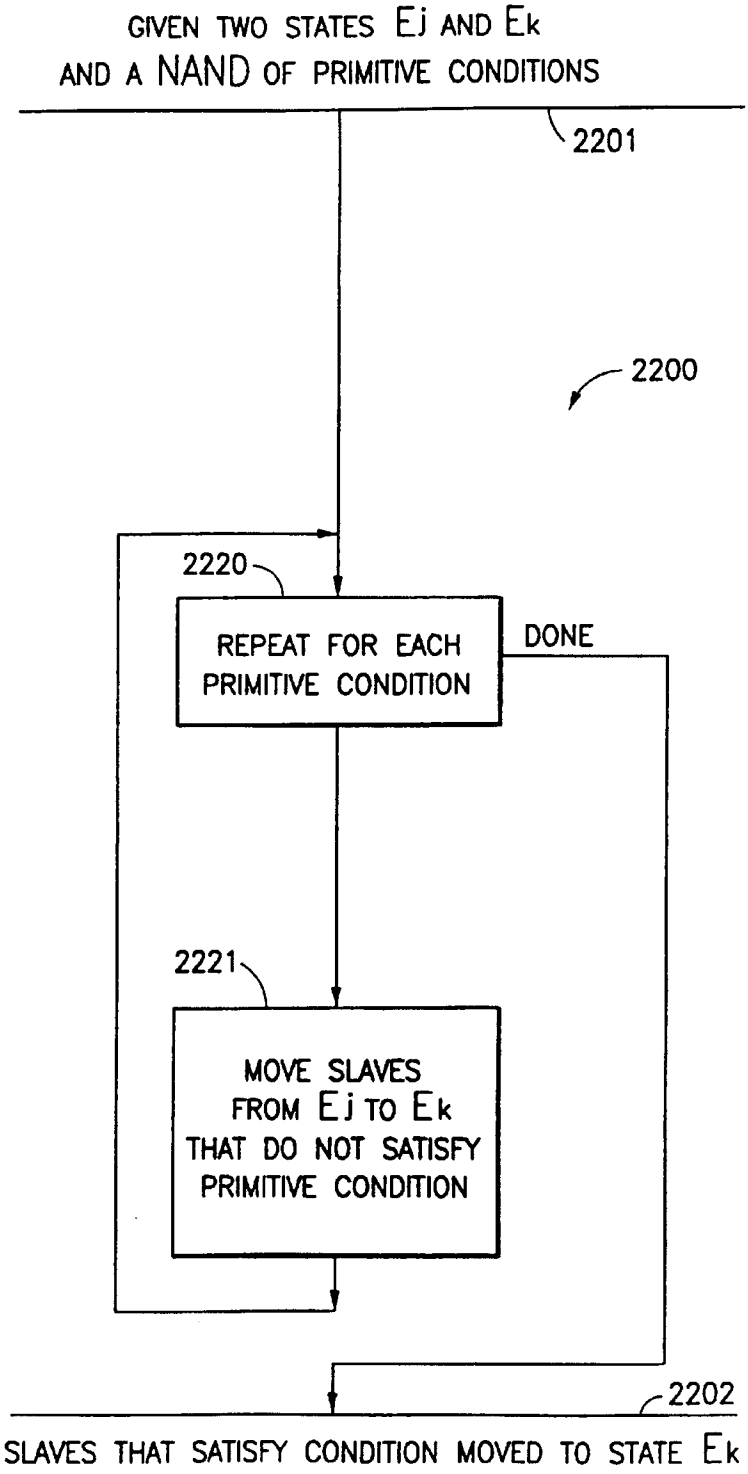

GIVEN TWO STATES Ej AND Ek
AND A NAND OF PRIMITIVE CONDITIONS
2201
2200
2220
REPEAT FOR EACH PRIMITIVE CONDITION
DONE
2221
MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY PRIMITIVE CONDITION
2202
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 22

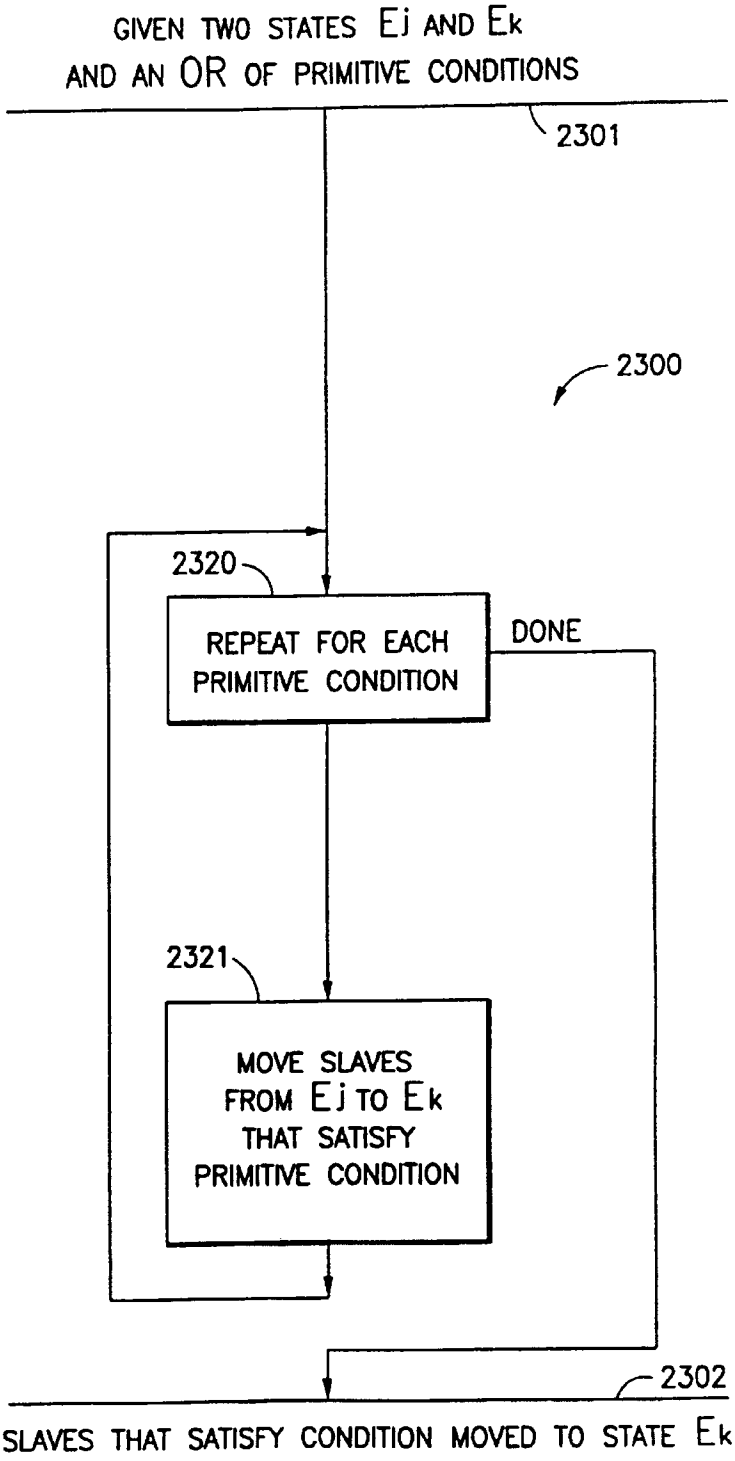

GIVEN TWO STATES Ej AND Ek
AND AN OR OF PRIMITIVE CONDITIONS
2301
2300
2320
REPEAT FOR EACH PRIMITIVE CONDITION
DONE
2321
MOVE SLAVES FROM Ej TO Ek THAT SATISFY PRIMITIVE CONDITION
2302
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 23

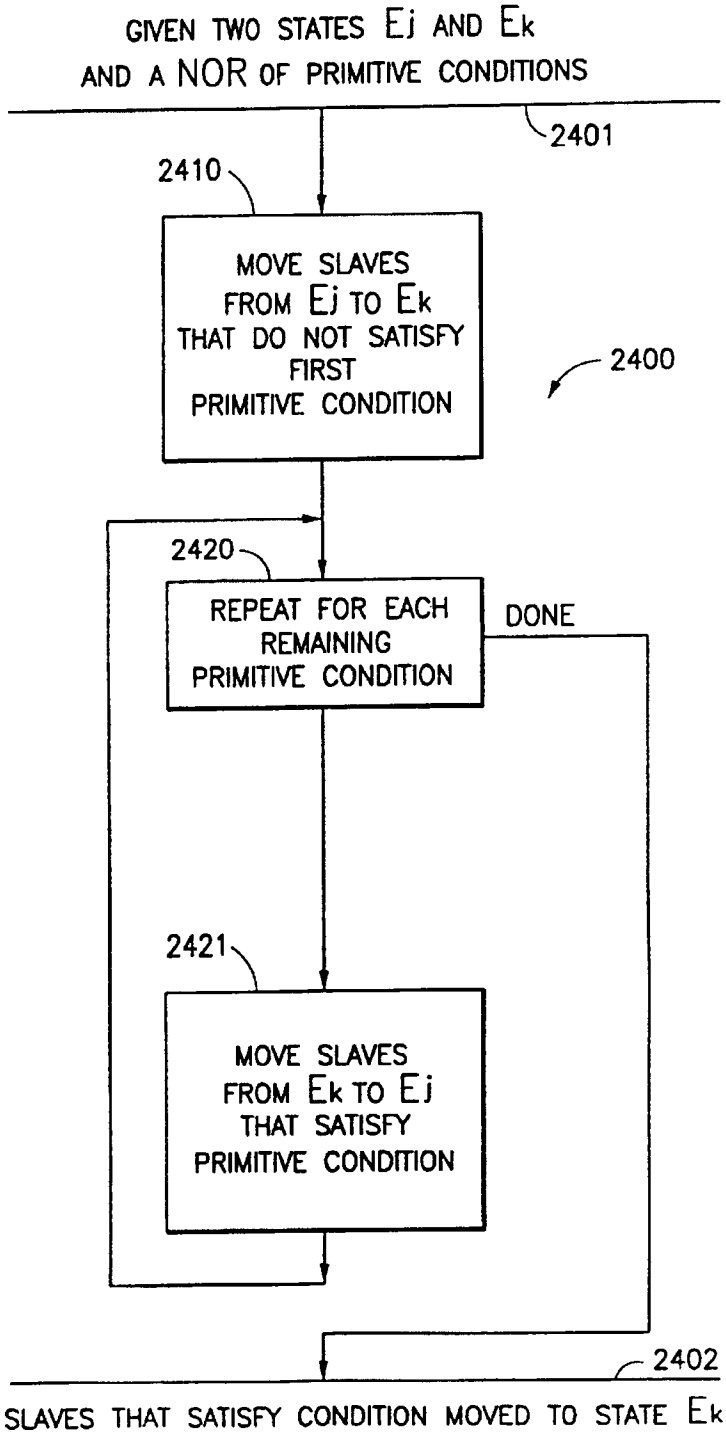

GIVEN TWO STATES Ej AND Ek
AND A NOR OF PRIMITIVE CONDITIONS
2401
2410
MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY FIRST PRIMITIVE CONDITION
2400
2420
REPEAT FOR EACH REMAINING PRIMITIVE CONDITION
DONE
2421
MOVE SLAVES FROM Ek TO Ej THAT SATISFY PRIMITIVE CONDITION
2402
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 24

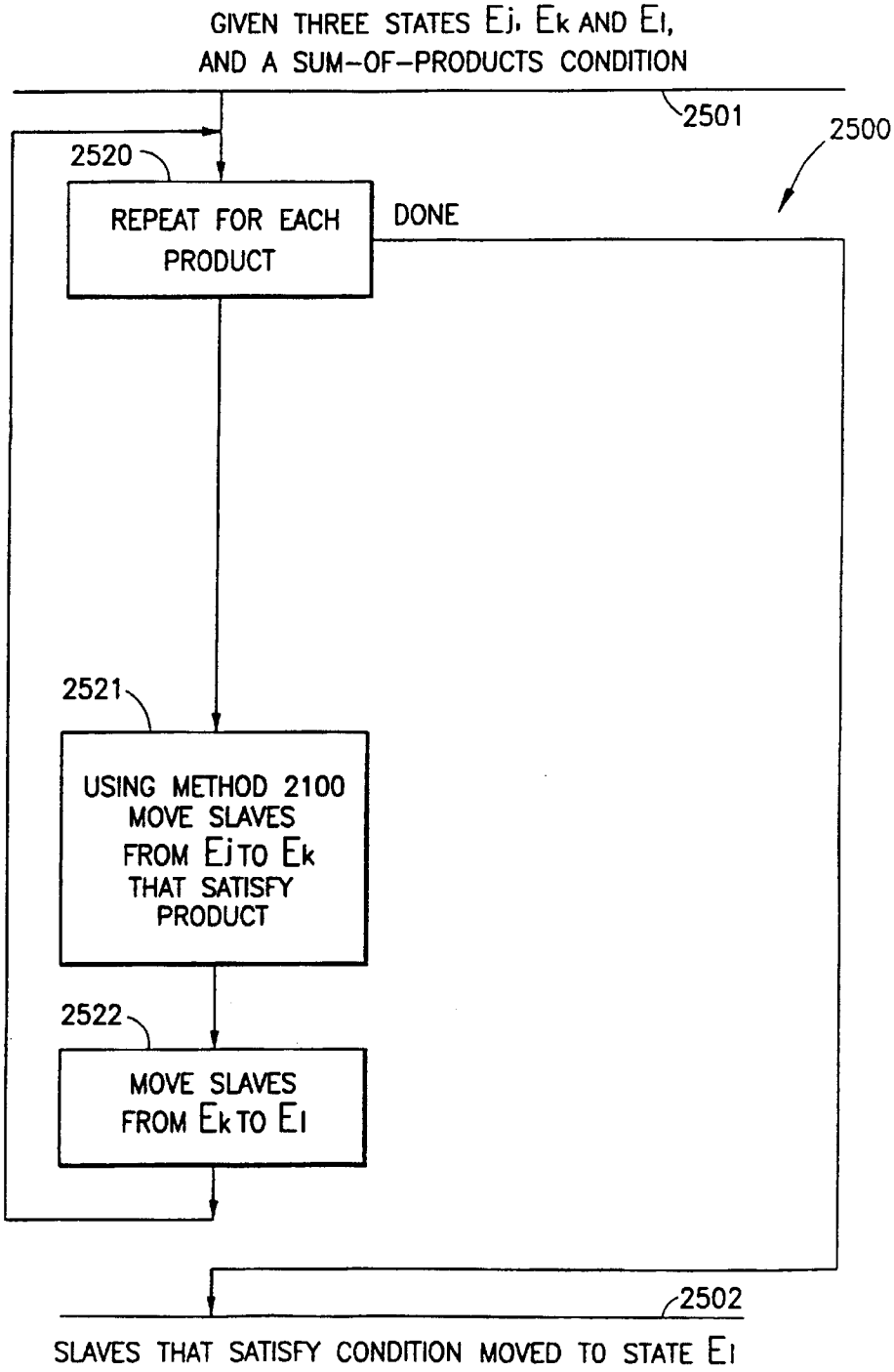

GIVEN THREE STATES Ej, Ek AND El,
AND A SUM-OF-PRODUCTS CONDITION
2501
2500
2520
REPEAT FOR EACH PRODUCT
DONE
2521
USING METHOD 2100 MOVE SLAVES FROM Ej TO Ek THAT SATISFY PRODUCT
2522
MOVE SLAVES FROM Ek TO El
2502
SLAVES THAT SATISFY CONDITION MOVED TO STATE El

FIG. 25

	2610	STATE 1	STATE 2	STATE 3
2600		1	0	0
2601	T12(~A)	A	~A	0
2602	T21(~B)	A+~B	~A*B	0
2603	T23(1)	A+~B	0	~A*B
2604	T12(A)	~A*~B	A	~A*B
2605	T21(B)	~A*~B+A*B	A*~B	~A*B
2606	T23(1)	~A*~B+A*B	0	~A*B+A*~B

FIG. 26

	2710	STATE 1	STATE 2	STATE 3
2700		1	0	0
2701	T12(A)	~A	A	0
2702	T21(~C)	~A+~C	A*C	0
2703	T23(1)	~A+~C	0	A*C
2704	T12(B)	~A*~B+~B*~C	~A*B+B*~C	A*C
2705	T21(~C)	~A*~B+~C	~A*B*C	A*C
2706	T23(1)	~A*~B+~C	0	A*C+B*C

FIG. 27

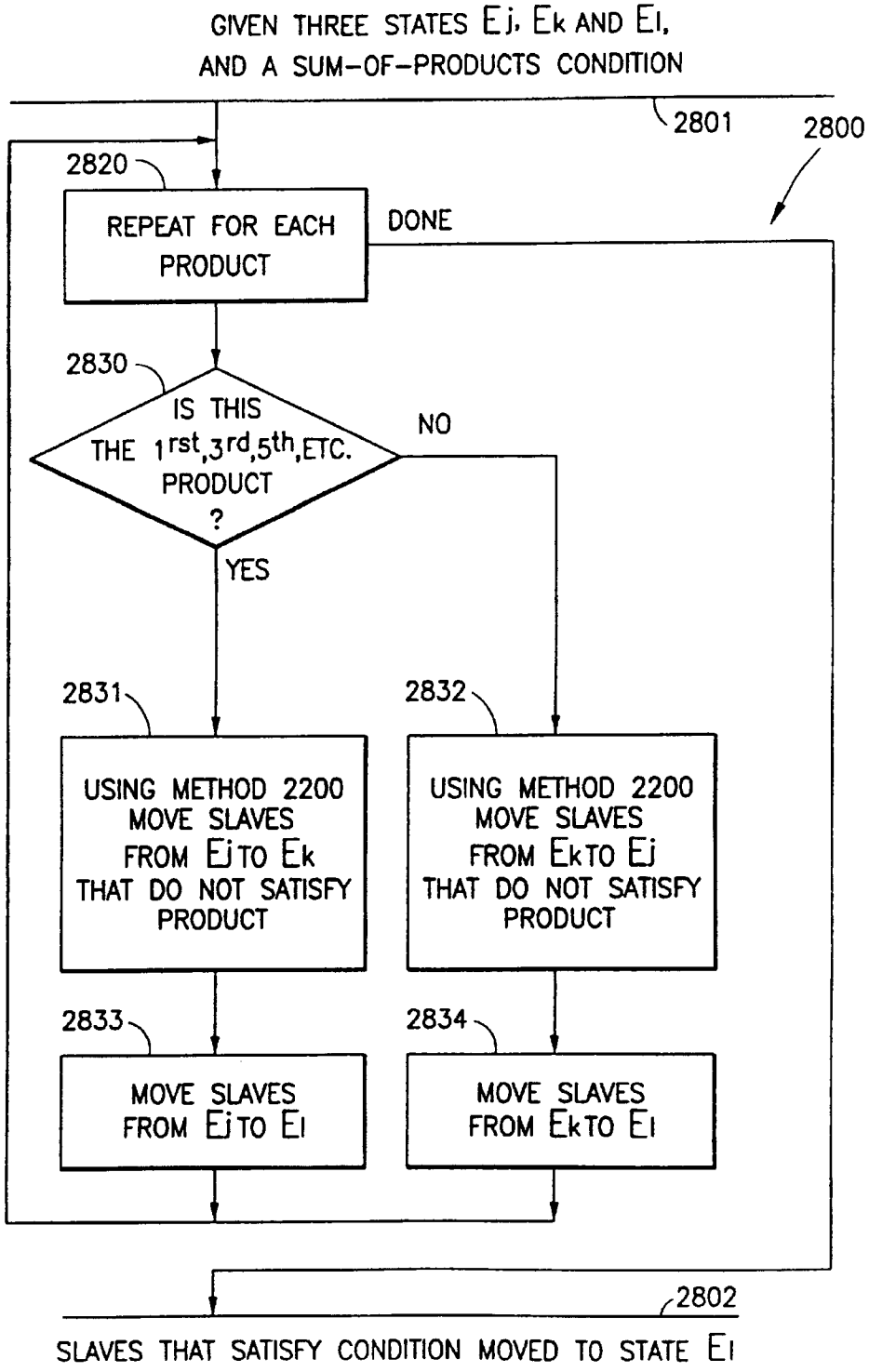

GIVEN THREE STATES Ej, Ek AND El,
AND A SUM-OF-PRODUCTS CONDITION
2801
2800
2820
REPEAT FOR EACH PRODUCT
DONE
2830
IS THIS THE 1rst,3rd,5th,ETC. PRODUCT ?
NO
YES
2831
USING METHOD 2200 MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY PRODUCT
2832
USING METHOD 2200 MOVE SLAVES FROM Ek TO Ej THAT DO NOT SATISFY PRODUCT
2833
MOVE SLAVES FROM Ej TO El
2834
MOVE SLAVES FROM Ek TO El
2802
SLAVES THAT SATISFY CONDITION MOVED TO STATE El

FIG. 28

	2910	STATE 1	STATE 2	STATE 3
2900		1	0	0
2901	T12(A)	~A	A	0
2902	T12(~B)	~A*B	A+~B	0
2903	T13(1)	0	A+~B	~A*B
2904	T21(~A)	~A*~B	A	~A*B
2905	T21(B)	~A*~B+A*B	A*~B	~A*B
2906	T23(1)	~A*~B+A*B	0	~A*B+A*~B

FIG. 29

	3010	STATE 1	STATE 2	STATE 3
3000		1	0	0
3001	T12(~A)	A	~A	0
3002	T12(~C)	A*C	~A+~C	0
3003	T23(1)	0	~A+~C	A*C
3004	T21(~B)	~A*~B+~B*~C	~A*B+B*~C	A*C
3005	T21(~C)	~A*~B+~C	~A*B*C	A*C
3006	T23(1)	~A*~B+~C	0	A*C+B*C

FIG. 30

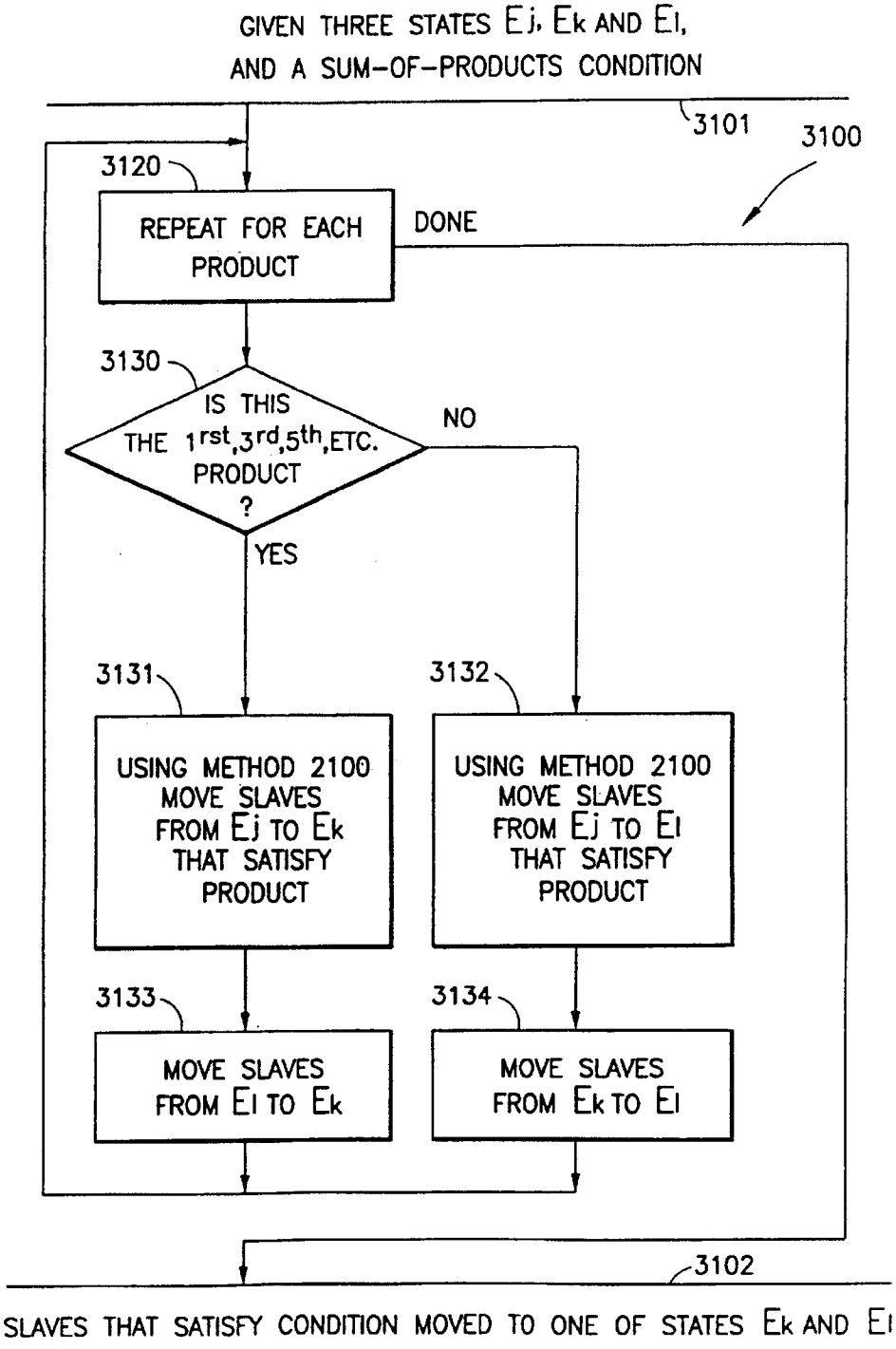

GIVEN THREE STATES Ej, Ek AND El,
AND A SUM-OF-PRODUCTS CONDITION
3101
3100
3120
REPEAT FOR EACH PRODUCT
DONE
3130
IS THIS THE 1rst,3rd,5th,ETC. PRODUCT ?
NO
YES
3131
USING METHOD 2100 MOVE SLAVES FROM Ej TO Ek THAT SATISFY PRODUCT
3132
USING METHOD 2100 MOVE SLAVES FROM Ej TO El THAT SATISFY PRODUCT
3133
MOVE SLAVES FROM El TO Ek
3134
MOVE SLAVES FROM Ek TO El
3102
SLAVES THAT SATISFY CONDITION MOVED TO ONE OF STATES Ek AND El

FIG. 31

	3210	STATE 1	STATE 2	STATE 3
3200		1	0	0
3201	T12(~A)	A	~A	0
3202	T21(~B)	A+~B	~A*B	0
3203	T32(1)	A+~B	~A*B	0
3204	T13(A)	~A*~B	~A*B	A
3205	T31(B)	~A*~B+A*B	~A*B	A*~B
3206	T23(1)	~A*~B+A*B	0	~A*B+A*~B

FIG. 32

	3310	STATE 1	STATE 2	STATE 3
3300		1	0	0
3301	T12(A)	~A	A	0
3302	T21(~C)	~A+~C	A*C	0
3303	T32(1)	~A+~C	A*C	0
3304	T13(B)	~A*~B+~B*~C	A*C	~A*B+B*~C
3305	T31(~C)	~A*~B+~C	A*C	~A*B*C
3306	T23(1)	~A*~B+~C	0	A*C+B*C

FIG. 33

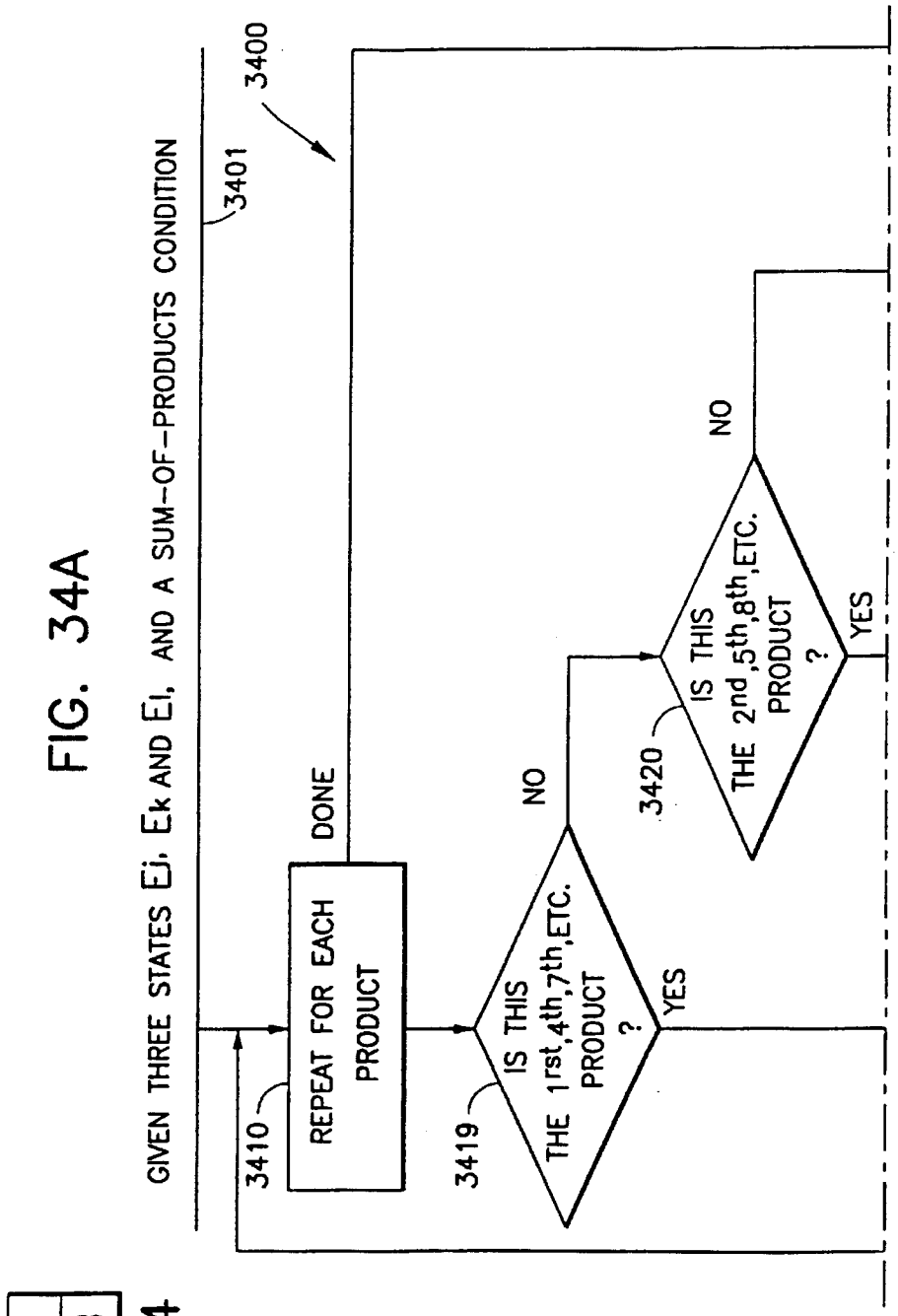


FIG. 34A

FIG. 34

FIG. 34A
FIG. 34B

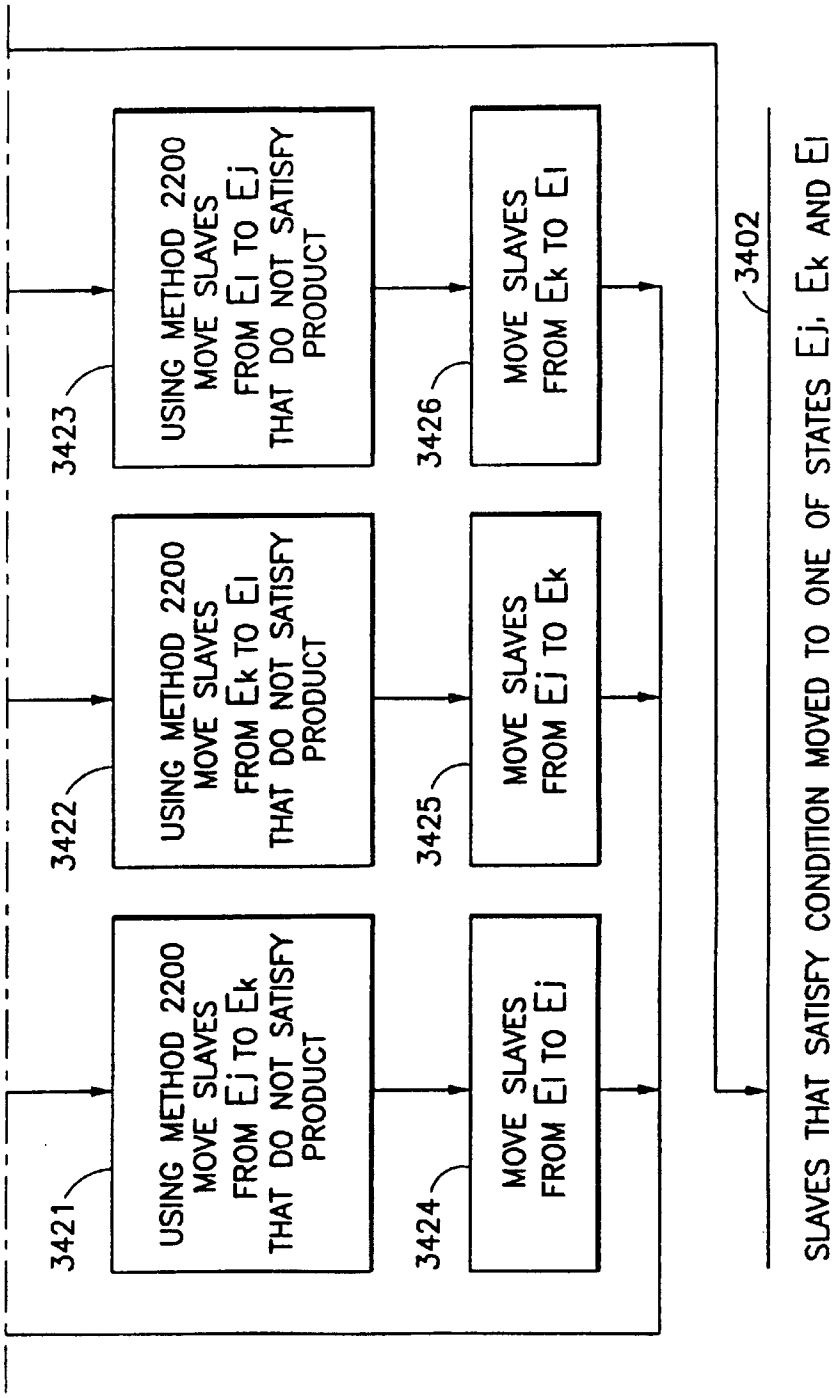

3421
USING METHOD 2200 MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY PRODUCT
3424
MOVE SLAVES FROM Ei TO Ej
3422
USING METHOD 2200 MOVE SLAVES FROM Ek TO Ei THAT DO NOT SATISFY PRODUCT
3425
MOVE SLAVES FROM Ej TO Ek
3423
USING METHOD 2200 MOVE SLAVES FROM Ei TO Ej THAT DO NOT SATISFY PRODUCT
3426
MOVE SLAVES FROM Ek TO Ei
3402
SLAVES THAT SATISFY CONDITION MOVED TO ONE OF STATES Ej, Ek AND Ei

FIG. 34B

	3510	STATE 1	STATE 2	STATE 3
3500		1	0	0
3501	T12(A)	~A	A	0
3502	T12(~B)	~A*B	A+~B	0
3503	T31(1)	~A*B	A+~B	0
3504	T23(~A)	~A*B	A	~A*~B
3505	T23(B)	~A*B	A*~B	~A*~B+A*B
3506	T12(1)	0	~A*B+A*~B	~A*~B+A*B

FIG. 35

	3610	STATE 1	STATE 2	STATE 3
3600		1	0	0
3601	T12(~A)	A	~A	0
3602	T12(~C)	A*C	~A+~C	0
3603	T31(1)	A*C	~A+~C	0
3604	T23(~B)	A*C	~A*B+B*~C	~A*~B+~B*~C
3605	T23(~C)	A*C	~A*B*C	~A*~B+~C
3606	T12(1)	0	A*C+B*C	~A*~B+~C

FIG. 36

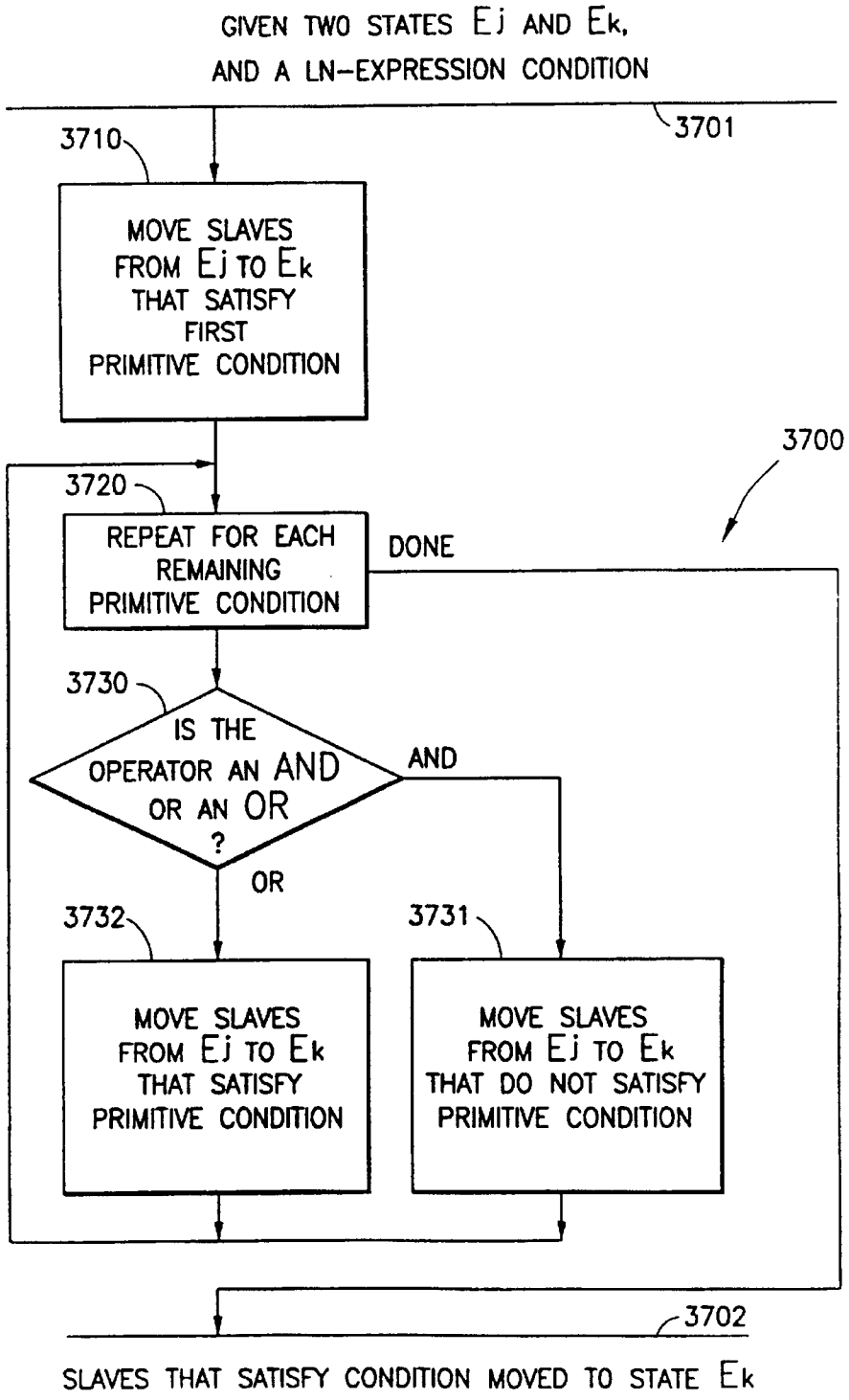

GIVEN TWO STATES Ej AND Ek,
AND A LN-EXPRESSION CONDITION
3701
3710
MOVE SLAVES FROM Ej TO Ek THAT SATISFY FIRST PRIMITIVE CONDITION
3700
3720
REPEAT FOR EACH REMAINING PRIMITIVE CONDITION
DONE
3730
IS THE OPERATOR AN AND OR AN OR ?
AND
OR
3732
MOVE SLAVES FROM Ej TO Ek THAT SATISFY PRIMITIVE CONDITION
3731
MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY PRIMITIVE CONDITION
3702
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 37

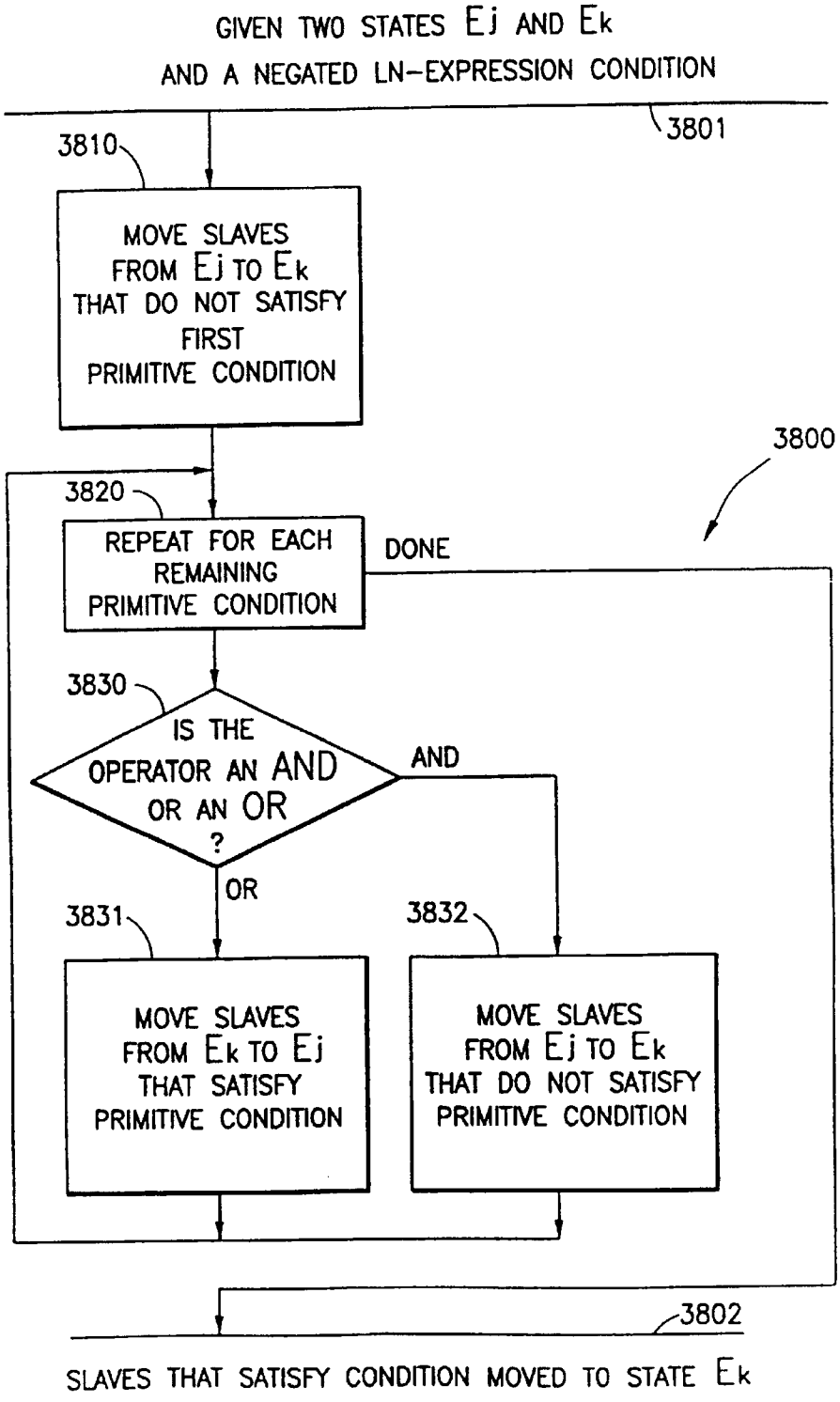

GIVEN TWO STATES Ej AND Ek
AND A NEGATED LN-EXPRESSION CONDITION
3801
3810
MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY FIRST PRIMITIVE CONDITION
3800
3820
REPEAT FOR EACH REMAINING PRIMITIVE CONDITION
DONE
3830
IS THE OPERATOR AN AND OR AN OR ?
AND
OR
3831
MOVE SLAVES FROM Ek TO Ej THAT SATISFY PRIMITIVE CONDITION
3832
MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY PRIMITIVE CONDITION
3802
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 38

3910	E1	E2	E3
3900	1	0	0
3901 T12(A)	~A	A	0
3902 T12(B)	~A*~B	A+B	0
3903 T21(~C)	~A*~B+~C	(A+B)*C	0

FIG. 39

4010	E1	E2	E3
4000	1	0	0
4001 T12(~A)	A	~A	0
4002 T21(B)	A+B	~A*~B	0
4003 T12(~C)	(A+B)*C	~A*~B+~C	0

FIG. 40

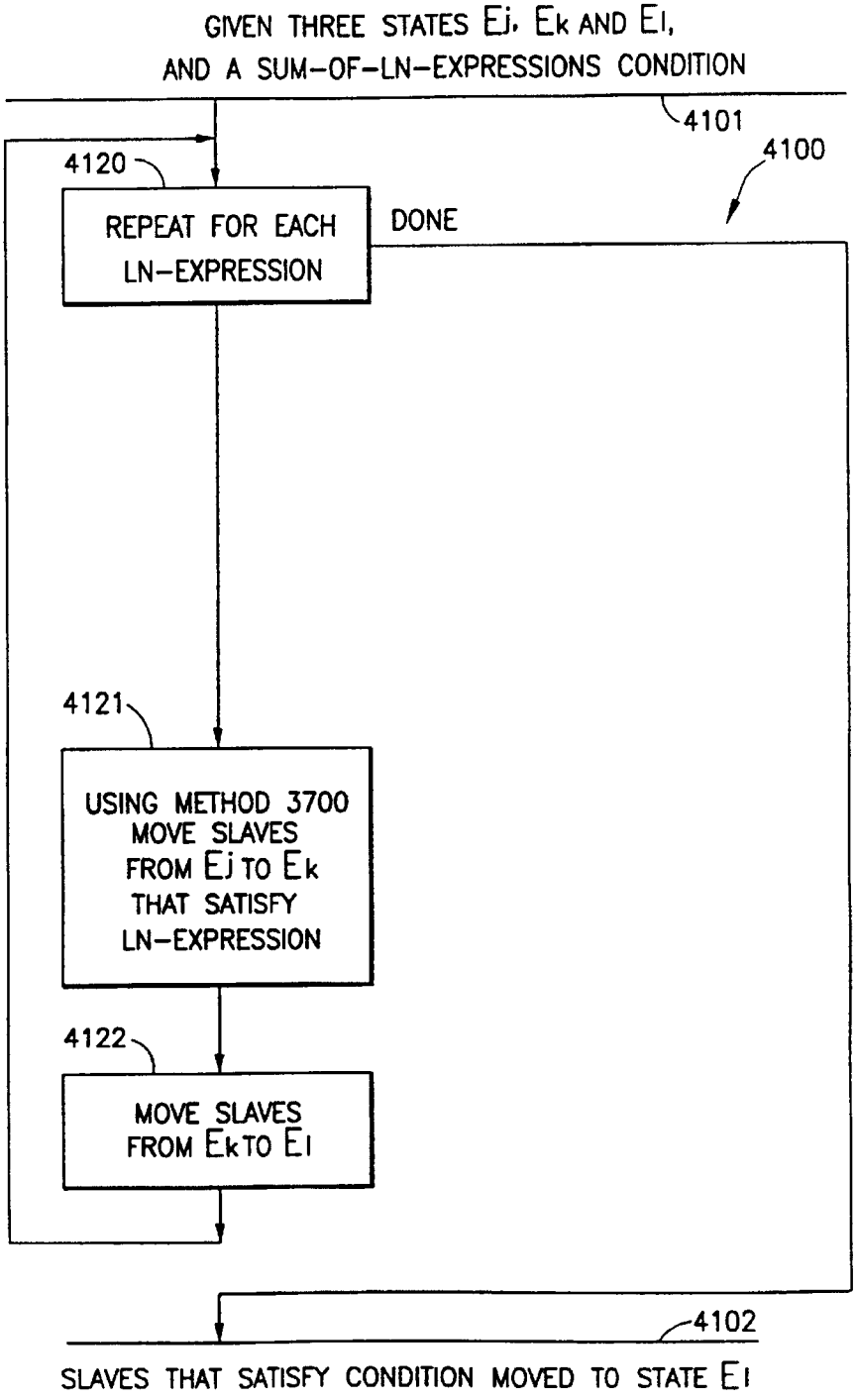

GIVEN THREE STATES Ej, Ek AND El,
AND A SUM-OF-LN-EXPRESSIONS CONDITION
4101
4100
4120
REPEAT FOR EACH LN-EXPRESSION
DONE
4121
USING METHOD 3700 MOVE SLAVES FROM Ej TO Ek THAT SATISFY LN-EXPRESSION
4122
MOVE SLAVES FROM Ek TO El
4102
SLAVES THAT SATISFY CONDITION MOVED TO STATE El

FIG. 41

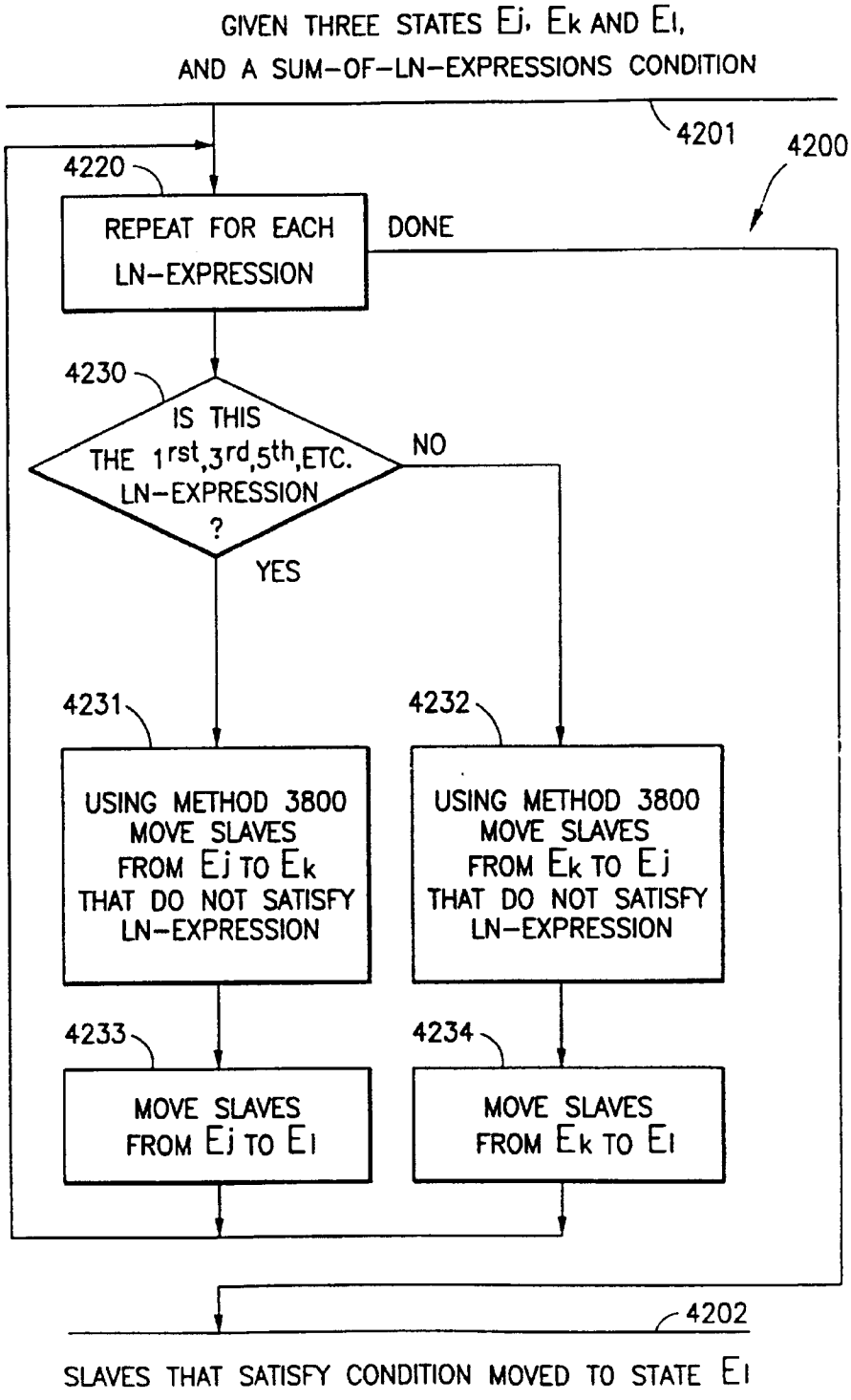

GIVEN THREE STATES Ej, Ek AND El,
AND A SUM-OF-LN-EXPRESSIONS CONDITION
4201
4200
4220
REPEAT FOR EACH LN-EXPRESSION
DONE
4230
IS THIS THE 1rst,3rd,5th,ETC. LN-EXPRESSION ?
NO
YES
4231
USING METHOD 3800 MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY LN-EXPRESSION
4232
USING METHOD 3800 MOVE SLAVES FROM Ek TO Ej THAT DO NOT SATISFY LN-EXPRESSION
4233
MOVE SLAVES FROM Ej TO El
4234
MOVE SLAVES FROM Ek TO El
4202
SLAVES THAT SATISFY CONDITION MOVED TO STATE El

FIG. 42

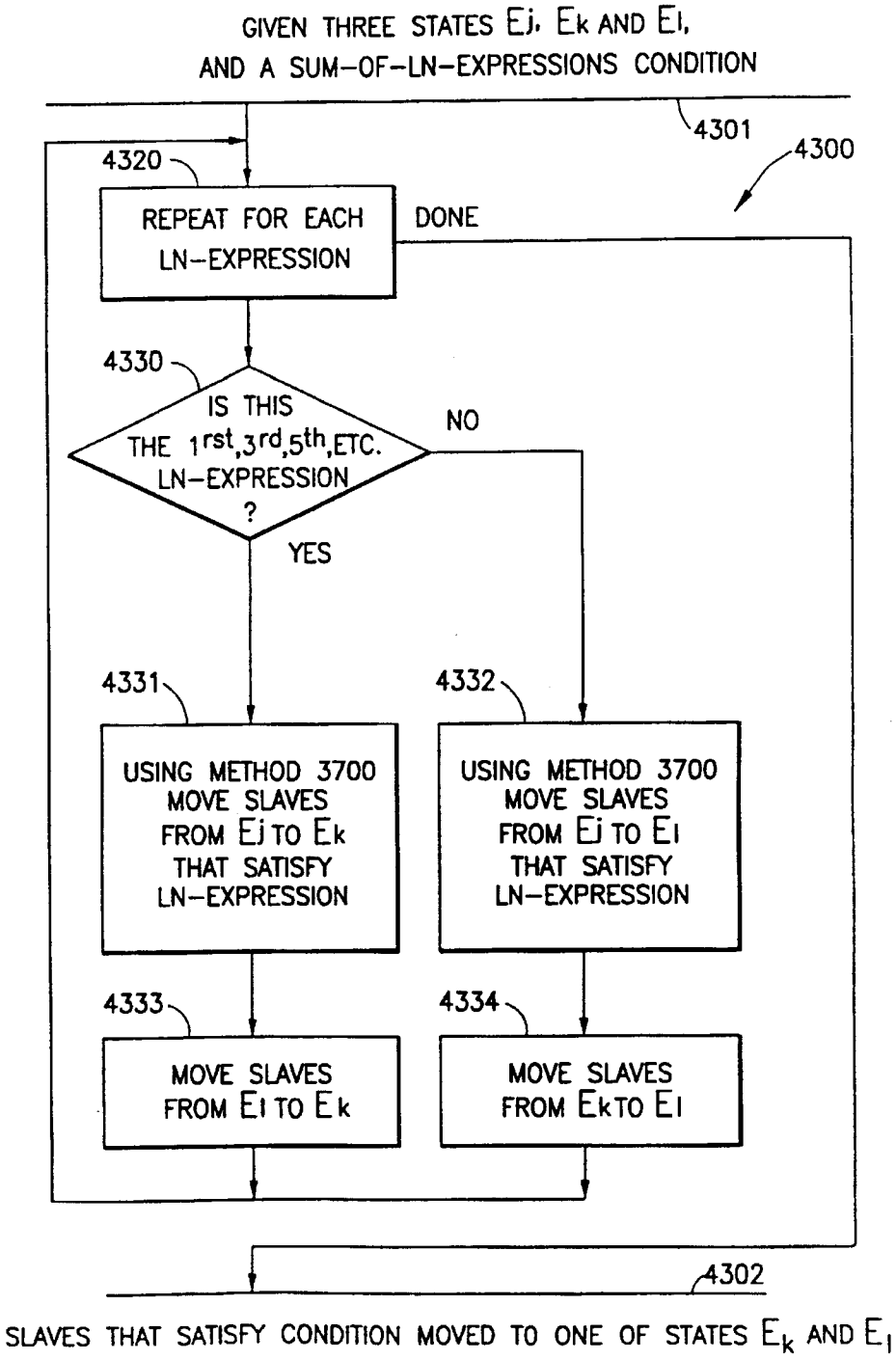

GIVEN THREE STATES Ej, Ek AND El,
AND A SUM-OF-LN-EXPRESSIONS CONDITION
4301
4300
4320
REPEAT FOR EACH LN-EXPRESSION
DONE
4330
IS THIS THE 1rst,3rd,5th,ETC. LN-EXPRESSION ?
NO
YES
4331
USING METHOD 3700 MOVE SLAVES FROM Ej TO Ek THAT SATISFY LN-EXPRESSION
4332
USING METHOD 3700 MOVE SLAVES FROM Ej TO El THAT SATISFY LN-EXPRESSION
4333
MOVE SLAVES FROM El TO Ek
4334
MOVE SLAVES FROM Ek TO El
4302
SLAVES THAT SATISFY CONDITION MOVED TO ONE OF STATES Ek AND El

FIG. 43

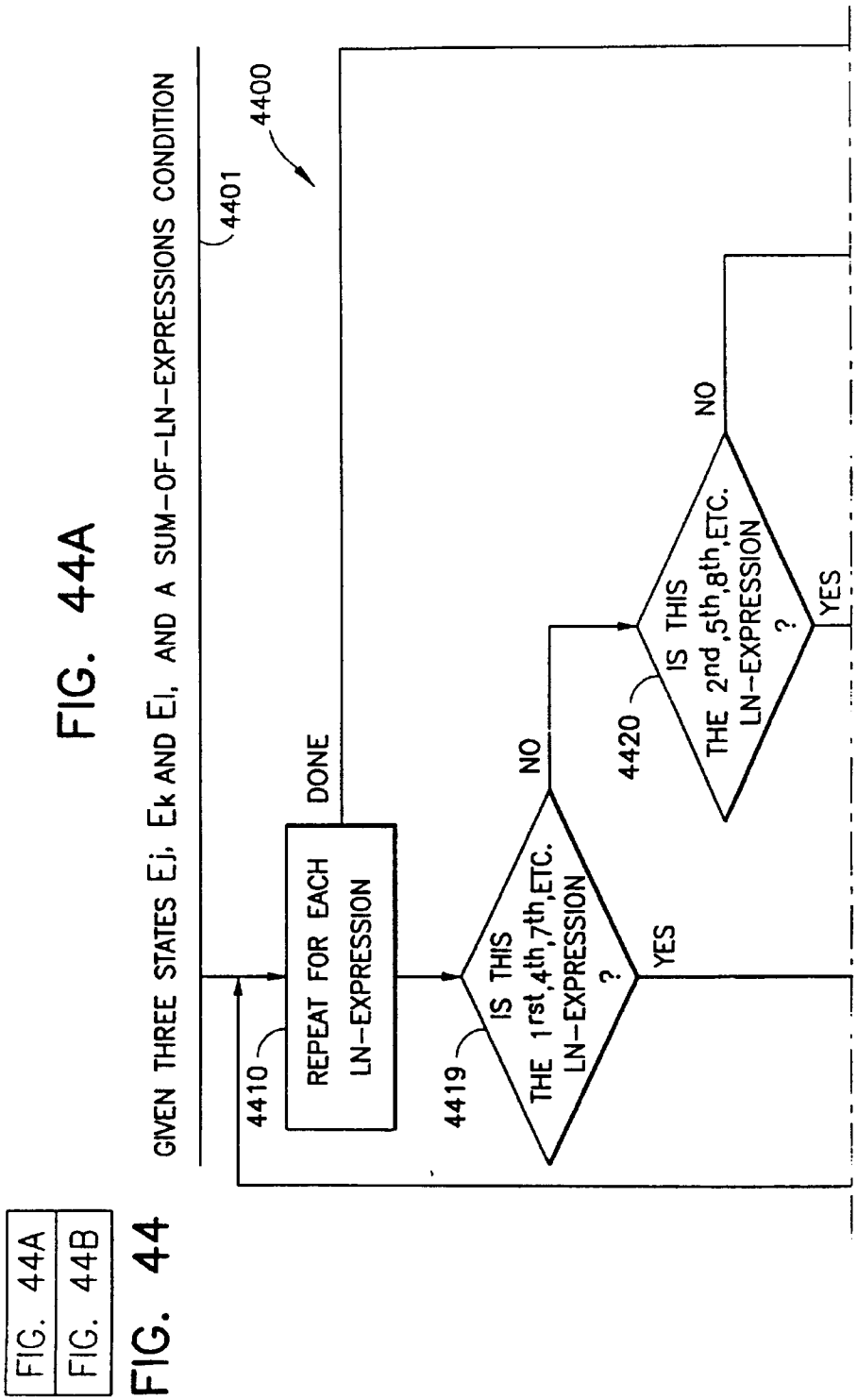


FIG. 44A

FIG. 44

FIG. 44A
FIG. 44B

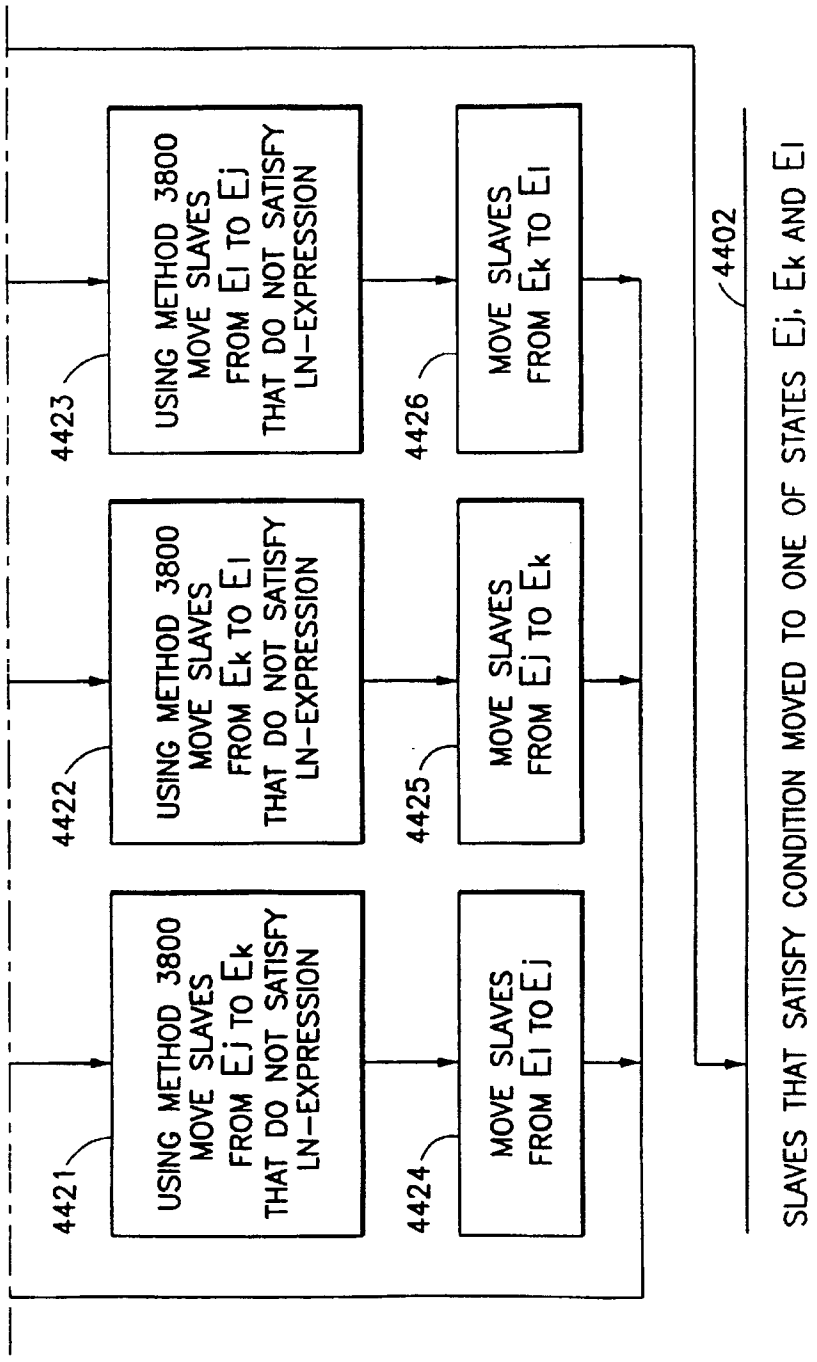

4421
USING METHOD 3800 MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY LN-EXPRESSION
4422
USING METHOD 3800 MOVE SLAVES FROM Ek TO Ei THAT DO NOT SATISFY LN-EXPRESSION
4423
USING METHOD 3800 MOVE SLAVES FROM Ei TO Ej THAT DO NOT SATISFY LN-EXPRESSION
4424
MOVE SLAVES FROM Ei TO Ej
4425
MOVE SLAVES FROM Ej TO Ek
4426
MOVE SLAVES FROM Ek TO Ei
4402
SLAVES THAT SATISFY CONDITION MOVED TO ONE OF STATES Ej, Ek AND Ei

FIG. 44B

SYSTEM AND METHOD FOR SELECTING A SUBSET OF AUTONOMOUS AND INDEPENDENT SLAVE ENTITIES

FIELD OF THE INVENTION

The invention relates to communications between a master station and one or more slave stations. More specifically, the invention relates to a master station selecting subset(s) of the slave stations by broadcasting commands with conditions that the selected slaves meet.

BACKGROUND OF THE INVENTION

In the prior art, a master control unit is to communicate with a plurality of autonomous and independent slaves. In such environment, the number of slaves is often not known a priori. There may in fact be no slaves with which the master can communicate. Among the reasons the master may have to communicate with the slaves are (a) the need to acknowledge their presence, (b) identify and count them and/or (c) order them to perform tasks. This kind of computational environment falls under the broader category of broadcasting sequential processes, which is defined by Narain Gehani in Chapter 9 of the book co-edited with Andrew McGettrick, "Concurrent Programming" (Addison-Wesley, 1988), which is herein incorporated by reference in its entirety.

Because the master often does not know ahead of time the number of slaves present and because that number may be very large and possibly unyieldy, it is advantageous for the master to be able to select a subset of the slaves with whom to communicate further. Such a selection must of course be done by a conditional. Those slaves that meet the condition are thus considered selected, while those that do not meet the condition are considered not selected. The selection is performed by broadcasting to all slaves the condition that must be met. This is akin to asking those among a large crowd of people whose last name is Lowell to raise their hand. Each slave is defined has having at least the capability to listen to the master's broadcasts, to receive the broadcast condition and to self-test so as to determine whether it meets the condition. See for example, U.S. patent application No. 08/303,965, entitled "Radio Frequency (RF) Group Select Protocol" to Cesar et al. filed on Sep. 9, 1994 which is herein incorporated by reference in its entirety.

Practical environments where this computational model can be applied include bus arbitration, wireless communication, distributed and parallel processing.

Characteristic of such environments is the existence of a protocol for how master and slaves communicate. The aforementioned capability of subset selection can be an important additional component of that protocol.

Finite state-machines are a well-known modelling tool. The set theory that often accompanies the definition of finite state-machines is also well known. Both subjects are amply covered in any of many books on discrete or finite mathematics that are available today. The book by Ralph Grimaldi, "Discrete and Combinatorial Mathematics: An Applied Introduction" (Addison-Wesley, 1985), is a fine example of its kind.

STATEMENT OF PROBLEMS WITH THE PRIOR ART

In the prior art, the methods used for selecting subsets of slaves is limited to comparisons against the information held by the slaves such that the comparison is either true or false and the slaves can be in either of two selection states: selected or not selected. The slave may contain many other states, but only two are effectively dedicated to the purpose of subset selection.

In some older prior art, a comparison will override a previous comparison. There is no notion of accumulating and combining successive comparisons to effect a selection according to a complex condition.

More recent prior art allows slaves to move between two selection states according to successive comparisons. That allows some complex conditions to be effected. However not all complex conditions can be effected with such two-selection-state machine. For example, the complex condition "is-red and is-not-tall or is-not-red and is-tall", that is, the EXCLUSIVE-OR of the two simple comparisons "is-red" and "is-tall", can not be performed such that the subset of slaves that satisfy the EXCLUSIVE-OR are in the first state and those that do not satisfy the EXCLUSIVE-OR are in the second state. In the case of complex conditions involving two comparisons and their negation, the two-selection-state machine can not perform the EXCLUSIVE-OR and the EQUIVALENCE logical operators. In the case of complex conditions involving more than two comparisons and their negation, the two-selection-state machine can not perform an increasingly large number of logical equations.

In the prior art, conditions such as the EXCLUSIVE-OR must be broken up into two independent processing steps. First, slaves satisfying the first AND term are selected and all necessary processing sequence is performed over them. Second, after a general reset, slaves satisfying the second AND term are selected and the same necessary processing sequence is repeated over those. That means that the processing sequence must be broadcast twice. In the case of more complicated conditions, rebroadcasting of such sequence may happen more than twice. For example, the condition (A*~B*~C)+(~A*B*~C)+(~A*~B+C) would need three rebroadcasts.

The only conditions that can be executed in a single round of broadcasting by a two-selection-state logic as used by the prior art are those conditions that can be expressed by a left-nested expression, such as ((A+B+C)*D*E)+F). OR conditions, such as (A+B+C+D), and AND conditions, such as (A*B*C), are particular cases of left-nested expressions. In contrast, EXCLUSIVE-OR type conditions, such as (A*B*~C)+(A*~B*C)*(~A*B*C), can not be written as left-nested expressions and therefore can not be handled by the two-selection-state logic.

Among the prior art is U.S. Pat. No. 5,434,572, entitled "System and Method for Initiating Communications between a Controller and a Selected Subset of Multiple Transponders in a Common RF Field" to Smith dated Jul. 18, 1995. The method begins by selecting all "transponder" in a field and, by a sequence of commands, incrementally moving groups of slaves to a "reset" condition.

In the U.S. Pat. No. 5,410,315, entitled "Group-Addressable Transponder Arrangement" to Huber dated Apr. 25, 1995, a selection is essentially made through a comparison against a "group and/or unit address". Unlike Smith, there is no progressive incremental refinement. Huber can perform only limited AND operations.

OBJECTS OF THE INVENTION

An object of this invention is a system and method for using arbitrarily complex logical conditions to select slave stations that satisfy those conditions transmitted by a master station through a series one or more commands.

An object of this invention is a system and method for using arbitrarily complex logical conditions to select RF transponders that satisfy those conditions transmitted by a base station through a series one or more commands.

SUMMARY OF THE INVENTION

The present invention is a system and method for selecting a subset of a plurality of autonomous and independent slaves, wherein each slave comprises (i) a three-state machine dedicated to selection, (ii) some other stored information, and (iii) a logic to execute externally provided commands in a command sequence that exercise the three-state machine. The primary purpose of the commands is to effect state transitions. The slave receives the command, which causes a comparison to be performed against the slave's stored information, the results of which possibly causing a state transition in the slave.

The commands, in a sequence called a command sequence, are broadcast from at least one master control unit to zero or more slaves. The exact number of slaves may not be known by the master. The master executes a method by which a sequence of discrete commands is broadcast to all slaves. The overall purpose of the method is to bring a subset of the slaves to be at the same state of their three-state machine, while all other slaves are at any one of the two other remaining states.

A three-state machine dedicated to selection is present in every slave. Each slave is at one of those three states, therefore, at any one time, the slaves can be sub-divided into three subsets: those slaves that have their selection three-state machine at the first state, those at the second state, and those at the third state. In a preferred embodiment, transitions are possible between any two states of the three-state machine. Transitions are requested by command (sequence) broadcast from the master. A command specifies a desired transition, say from the second state to the first state. Only slaves that are at the second state may be affected. The command also specifies a condition under which the transition will occur. If the condition is met, the transition is effected; if not, the slave remains in its previous state.

In a preferred embodiment, slaves can be moved from a first state to a second state and visa versa. Only slaves in the second state can be moved to a third state. The slaves in the third state ignore the remaining commands in the command sequence. In alternative preferred embodiments, the first and second states reverse roles after an end of one or more subsequences in the sequences of commands. Also, the second and third states can reverse roles after an end of one or more subsequences. Further, the states of the slaves can cycle their roles at the end of one or more of the subsequences.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of preferred embodiments of the invention with reference to the drawings that are included:

FIG. **1** is a block diagram of a master control unit broadcasting commands to a plurality of slaves.

FIG. **2** is a block diagram of the components of a master control unit.

FIG. **3** is a block diagram of the components of a slave.

FIG. **4** shows a state diagram showing a three-state machine that allows all six possible transitions between any two different states.

FIG. **5** shows a state diagram showing a three-state machine that allows five possible transitions between any two different states.

FIG. **6** shows a state diagram showing a three-state machine that allows four possible transitions between any two different states, such that any state is reachable from any other state.

FIG. **7** shows a state diagram showing a three-state machine that allows four possible transitions between any two different states, such that any state is reachable from any other state and two of the states have no transitions between them.

FIG. **8** shows a state diagram showing a three-state machine that allows three possible transitions between any two different states, such that any state is reachable from any other state.

FIG. **9** lists all possible three-state machines that can be used for the purposes of this invention.

FIG. **10** is a set theoretic representation of how the plurality of slaves is subdivided into at most three sets.

FIG. **11** describes what happens when a command to transfer slaves that satisfy some condition from one state to another is broadcast.

FIGS. **12**, **13**, **14**, **15**, **16** and **17** exemplifies by means of Venn diagrams how a command transfers elements from one set to another.

FIGS. **18**, **19** and **20** show sequences of commands for selecting a subset of slaves that satisfy an EXCLUSIVE-OR condition and such that those slaves end up in a first, second and third set, respectively

FIG. **21** describes a method that computes a product (AND) condition.

FIG. **22** describes a method that computes a negated product (NAND) condition.

FIG. **23** describes a method that computes a sum (OR) condition.

FIG. **24** describes a method that computes a negated sum (NOR) condition.

FIG. **25** describes a method that computes a condition written in sum-of-products form whereby the product terms are built in a second state and the sum is accumulated in a third state.

FIGS. **26** and **27** exemplify the use of the method described in FIG. **25**.

FIG. **28** describes a method that computes a condition written in sum-of-products form whereby the product terms are built alternatively in a first and second states and the sum is accumulated in a third state.

FIGS. **29** and **30** exemplify the use of the method described in FIG. **28**.

FIG. **31** describes a method that computes a condition written in sum-of-products form whereby the product terms are built alternatively in a second and third states and the sum is accumulated in that second and third state, respectively.

FIGS. **32** and **33** exemplify the use of the method described in FIG. **31**.

FIG. **34** describes a method that computes a condition written in sum-of-products form whereby the product terms are built alternatively in a first, second and third states and the sum is accumulated in that first, second and third state, respectively.

FIGS. **35** and **36** exemplify the use of the method described in FIG. **31**.

FIG. **37** describes a method that computes a single left-nested expression using only two states.

FIG. **38** describes a method that computes the negation of a single left-nested expression using only two states.

FIG. **39** exemplifies the use of the method described in FIG. **37**.

FIG. **40** exemplifies the use of the method described in FIG. **38**.

FIG. **41** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built in a second state and the sum is accumulated in a third state.

FIG. **42** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built alternatively in a first and second states and the sum is accumulated in a third state.

FIG. **43** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built alternatively in a second and third states and the sum is accumulated in that second and third states, respectively.

FIG. **44** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built in a first, second and third states and the sum is accumulated in that first, second and third states, respectively.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** shows least one master control unit **101** communicating with a plurality of autonomous and independent slaves **102**. The communication medium **103** can be in terms of either direct electric contact means or electromagnetic radiation means, e.g., radio frequency (RF) embodiments. However, it also encompasses light, sound and other frequencies utilized for signalling purposes. Master unit **101** is capable of broadcasting commands at the plurality of slaves **102** via communication medium **103**. Each slave is capable of receiving the broadcast commands which are processed by logic **150**. For example, U.S. Pat. No. 4,656,463 to Anders et al. shows an RF tag systems where for our purposes the active transceiver (AT) would be the master control unit **101**, the passive transceivers (PT) would be the independent slaves **102**, and the communication medium **103** would be RF over free space. In an alternative preferred embodiment, U.S. Pat. No. 5,371,852 to Attanasio et al. shows a cluster of computers where for our purposes the gateway would be the master unit **101**, the nodes in the cluster would be the slaves **102**, and the communication medium **103** would be the interconnect. These references are incorporated by reference in their entirety.

FIG. **2** shows that a master unit **200** comprises (a) means **201** for broadcasting commands from a command set **250** to a plurality of slaves, and (b) processing means **202** for determining the correct sequence of commands to be broadcast. In one embodiment, processing means **202** are proximate to broadcast means **201**. Other embodiments are possible where processing means **202** and broadcast means **201** are remote from each other.

FIG. **3** shows that a slave **300** comprises (a) a receiver **301** for receiving commands from a master, (b) a three-state machine **304**, (c) a memory with stored information **303** (d) processor or logic **302** for executing any received command, performing any condition testing over the stored information **303** as specified by the command, and effecting a state transition on three-state machine **304** conditional to the result of the condition testing. Receiving means **301** and broadcasting means **201** must be necessity be compatible. The receiving means **301** are well known. For example in RF tagging, radio frequency receivers/transmitters are used. In the networking arts standard connections to networks and/or information buses are used. Stored information **303** is typically embodied in the form of registers and/or memory.

The three-state machine **304** comprises a select state, a first unselect state, and a second unselect state state. All three of these states can be used in the selection and unselection of sets of slaves. The logic **302** is further described below.

The significant difference between a two and a three-selection-state machine is that, using any sequence of commands, the former can only isolate or select slaves that satisfy a condition expressed by a left-nested expression. Using a two-selection-state machine, there is no sequence of commands that can process conditions that are expressed as as a SUM-of-left-nested-expressions.

Only a three-selection-state machine can select slaves that satisfy a condition expressed by a sum-of-left-nested-expression. Further, a three-selection-state machine is also sufficient to select a set of slaves that satisfy any arbitrary condition, even though those conditions are expressed by a sum-of-left-nested-expression. Therefore adding a fourth, fifth, etc. state does not add any new capability to the selection logic. In addition, since any condition can be expressed by a sum-of-left-nested expression, a three-selection-state machine can select a set of slave satisfying any possible condition. This capability is undisclosed and unrecognized in the prior art.

The invention enables this capability because a separate condition (or set of conditions), each corresponding to a set of slaves, can be isolated in any one of the three states at any given time. Therefore, operations on two sets of conditions, in two of the respective states, can be performed without affecting or being affected by the conditions held in the third state.

In one embodiment, receiving means **301**, processing means **302**, stored information **303**, and three-state machine **304** are proximate. Other embodiments are possible where the components **301**, **302**, **303** and **304** are remote from each other, in part or completely.

The three states are dedicated to the process of determining whether a slave satisfies an arbitrarily complex condition. During the process of determining whether the slave satisfies the condition, the slave may be in any of the three states as dictated by the process. If the slave does not satisfy the condition, the process assures that the slave will end up at a state that enables the slave to communicate further with the master.

Three-state machine **304** is part of every slave. A preferred three-state machine is shown in FIG. **4**. Three-state machine **400** includes the three states **401**, **402** and **403**, and all six possible state-to-state transitions **412**, **413**, **421**, **423**, **431** and **432**, where the transitions are between two different states. The three states **401**, **402** and **403** are named S1, S2 and S3, respectively. A transition from a state to itself is not helpful for the methodology described herein.

Other three-state machines are possible. In FIG. **5**, three-state machine **500** has only five of the six state-to-state transitions present in three-state machine **400**. Three-state machine **500** represents a class of six possible three-state machines where one of the six possible state-to-state transitions is inoperative. In the particular case of FIG. **5**, transition **413** is inoperative.

In FIG. **6**, three-state machine **600** has only four of the six state-to-state transitions of three-state machine **400**. The four operative transitions are such that any state can be reached from another state by means of one or two transitions. Moreover there is at least one possible transition between any two states. Three-state machine **600** represents a class of six possible three-state machines were two of the six possible state-to-state transitions are inoperative, while still providing access to any state from any other state. In the particular case of FIG. **6**, transitions **413** and **432** are inoperative.

In FIG. **7**, three-state machine **700** has only four of the six state-to-state transitions of three-state machine **400**. The four operative transitions are such that any state can be reached from another state by means of one or two transitions. Moreover there are two states between which there is no possible transition. Three-state machine **700** represents a class of three possible three-state machines where one of the pairs of transitions between two states is inoperative. In the particular case of FIG. **7**, the pair of transitions **413** and **431** between states **401** and **403** is inoperative.

In FIG. **8**, three-state machine **800** has only three of the six state-to-state transitions of three-state machine **400**. The three operative transitions are such that any state can be reached from another state by means of one or two transitions. Therefore each pair of states is connected by one and only one transition, in such a way that all transitions move either clockwise or anticlockwise. Three-state machine **800** represents a class of two possible three-state machines that have only three of the six state-to-state transitions. In the particular case of FIG. **8**, the three operative transitions **412**, **423** and **431** define an anticlockwise cycle.

All three-state machines relevant to this invention are listed in FIG. **9**. The six state-to-state transitions **412**, **421**, **423**, **432**, **431** and **413** are named T12, T21, T23, T32, T31 and T13, respectively. Each row defines one possible three-state machine. For each state-to-state transition, the existence or not of that transition is indicated. The three-state machine defined by row **900** is a preferred embodiment that corresponds to three-state machine **400** of FIG. **4**. The three-state machines defined by rows **901**, **902**, **903**, **904**, **905**, and **906** belong to the class of three-state machine **500** of FIG. **5**. The three-state machines defined by rows **907**, **908**, **909**, **910**, **911**, and **912** belong to the class of three-state machine **600** of FIG. **6**. The three-state machines defined by rows **913**, **914**, and **915** belong to the class of three-state machine **700** of FIG. **7**. The three-state machines defined by rows **916** and **917** belong to the class of three-state machine **800** of FIG. **8**.

At any one time, each slave is at one and only one of the three states **401**, **402**, or **403**. Accordingly, there are three sets of slaves; those are state **401**, those are state **402**, and those at state **403**. State transitions are equivalent to movement between those three sets. This view of operating over sets is illustrated in FIG. **10**. Set **1001**, named E1, contains as elements all slaves **1010** that are at state **401**. Set **1002**, named E2, contains as elements all slaves **1020** that are at state **402**. Set **1003**, named E3, contains as elements all slaves **1030** that are at state **403**. There are six base commands, irrespective of the condition they specify, for effecting movement of elements between those three sets. Command **1012**, named T12, moves elements from set **1001** to set **1002**. Command **1021**, named T21, moves elements from set **1002** to set **1001**. Command **1023**, named T23, moves elements from set **1002** to set **1003**. Command **1032**, named T32, moves elements from set **1003** to set **1002**. Command **1031**, named T31, moves elements from set **1003** to set **1001**. Command **1013**, named T13, moves elements from set **1001** to set **1003**.

The simplest form of command is illustrated in FIG. **11**. Command **1110** comprises three parameters. First, the "from" state **1101**; second, the "to" state **1102**; and third, the primitive condition **1112** which must be satisfied for the transition to happen. Those three parameters are named Si, Sj, and s, respectively in the figure. Si, the "from" state **1101**, and Sj, the "to" state **1102**, can be any of the three states **401**, **402** or **403**, except that Si and Sj are not equal.

The primitive condition may take many forms depending on the overall capabilities of the slaves and the purposes that underlie the need for selecting subsets of slaves. Such primitive conditions could take the form of equality testing or numerical comparisons. Even though a single command broadcast from the master to the slave can only specify a single primitive condition, arbitrarily complex conditions are realized by a sequence of these primitive commands. In a preferred embodiment, an arbitrarily complex condition is described by a logical equation over primitive conditions. For example, the complex condition A*B+~A*~B, where A and B are primitive conditions, "*" is the binary logical operator AND, "+" the binary logical operator OR, and "~" the unary logical operator NOT. Negated primitive conditions, such as ~A, are assumed to be primitive conditions.

It is convenient for expositional purposes to textually represent command **1110**. A simple syntax used herein is to write the command as Tij(s), where i and j are **1**, **2**, or **3**, corresponding to states **401**, **402**, **403**, respectively, and s is the condition to be satisfied. The prefix T, for transition, is purely cosmetic. For example, T31(~A) represents a command to move all slaves that are at the third state and which do not satisfy A, to the first state, while T23(1) represents a command to move all slaves that are at the second state to the third state unconditionally.

The six possible transitions **412**, **413**, **421**, **423**, **431** and **432** for some condition s, can thus be written has T12(s), T13(s), T21(s), T23(s), T31(s) and T32(s), respectively. Any command thus involves only two of the three states of a three-state machine and only one of the six possible transitions. The pair of states **1100** in FIG. **11** and the single transition between them defines the scope of a single command. Only slaves that are at state Si, that is the "from" state **1101**, of the pair of states **1100** are allowed to transition, and those that do transition will do it to state Sj, that is the "to" state **1102**. Condition s is tested by each slave that is at state Si. Those for which the condition is satisfied will switch to state Sj. These semantics are expressed by the two logical expressions

$$Ei=Ei*\sim s$$

$$Ej=Ej+Ei*s$$

The first expression states that the set Ei, of all slaves that are at state Si, is decremented by the number of slaves that move from Si to Sj. That is expressed in the form of a logical AND between the previous value of set Ei and the virtual set of all slaves in Ei that did not satisfy condition s. Concurrently, the second expression states that the set Ej, of all slaves that are at state Sj, is augmented by the number of slaves that have moved from Si to Sj. That is expressed in the form of a logical OR between the previous value of set Ej and the virtual set of all slaves in Ei that satisfy condition s, the latter expressed by a logical AND between the previous value of set Ei and the virtual set of all slaves in Ei that satisfy condition s.

Since a command **1110** is broadcast to all slaves and they receive and operate on it concurrently, the command is essentially an operation over sets. The command Tij(s) effectively moves elements from a set Ei, of all slaves at state Si, to a set Ej, of all slaves at state Sj. Therefore sets E1, E2 and E3 are associated to states S1, S2 and S3, respectively. Those two notions, sets and states, are for the purpose of this invention functionally equivalent. Reference herein to states S1, S2 and S3 imply sets E1, E2 and E3, and vice versa, respectively.

FIG. **12** illustrates by means of Venn diagrams a simple non limiting example of one of such command. Sets **1001**, **1002** and **1003** correspond to slaves that are in the first, second and third state, respectively. For this example, set **1001** initially contains all slaves, while sets **1002** and **1003** are empty. Three testable primitive conditions A, B and C are defined. Each one of these three primitive conditions defines a virtual subset **1205**, **1206** and **1207**, respectively. The negation of each primitive condition, namely ~A, ~B and ~C, defines three complementary virtual subsets to **1205**, **1206** and **1207**, respectively. Those virtual subsets may or may not have slaves in common. In the figure we assume the most difficult case where virtual subsets **1205**, **1206** and **1207** intersect each other. Command T12(A) is broadcast, which forces all slaves in virtual subset **1205** in set **1001** to move from set **1001** to set **1002**. Therefore, after the command is executed by all slaves in this situation, the right half of the figure shows that set **1001** represents the ~A condition, set **1002**, the A condition, and set **1003** is empty.

Note that other Figures in this disclosure that are Venn diagrams have there sets numbered in the same manner as FIG. **12** but that these number are not shown for clarity.

Another example is shown in FIG. **13**. The starting configuration is the same as in FIG. **12**. However, the command T12(~A) is broadcast instead. As the right half of the figure indicates, after the command is executed by all slaves in this situation, set **1001** represents the A condition, set **1002**, the ~A condition, and set **1003** is empty.

A condition that is the product of two or more primitive conditions is obtained by two or more commands. An AND condition A*B, for example, can be obtained by broadcasting two or more commands. First, T12(A), then T21(~B). Starting from the same initial configuration as used in FIG. **12**, execution of T12(A) is shown in FIG. **12**. Execution of command T21(~B) on that resulting configuration is shown in FIG. **14**. As the right half of the figure indicates, after the two commands are executed in succession by all slaves in this situation, set **1001** represents the ~(A*B) condition, set **1002**, the A*B condition, and set **1003** is empty. Therefore, set **1002** represents an AND condition, while set **1001** represents the complementary NAND condition.

A condition that is the sum of two or more primitive conditions is obtained by two or more commands. An OR condition A+B, for example, can be obtained by broadcasting two commands. First, T12(A), then T12(B). Starting from the same initial configuration as used in FIG. **12**, execution of T12(A) is shown in FIG. **12**. Execution of command T12(B) on that resulting configuration is shown in FIG. **15**. As the figure indicates, after the two commands are executed in succession by all slaves in this situation, set **1001** represents the ~(A+B) condition, set **1002**, the A+B condition, and set **1003** is empty. Therefore, set **1002** represents an OR condition, while set **1001** represents the complementary NOR condition.

The previous two examples involve only two of the possible three sets. Some conditions require the use of all three sets. The only two conditions involving two primitive conditions A and B that require all three sets are the EXCLUSIVE-OR, A*~B+~A*B, and its complement the EQUIVALENCE, A*B+~A*~B. (See discussion of left nested expressions below.) The EXCLUSIVE-OR can be obtained by broadcasting a sequence of three commands. T12(~A), T13(B) and T21(B). Execution of the three commands is shown in FIGS. **13**, **16**, and **17**. This sequence is more compactly represented in tabular form as done in FIG. **18**. Row **1800** of the table is the initial state of the three sets. In this example, set **1001** has all slaves and sets **1002** and **1003** are empty. Rows **1801**, **1802** and **1803** show the result of executing commands T12(~A), T13(B) and T21(B), respectively, and the resulting conditions expressed by each of the three sets after each command is executed. As FIG. **18** shows, after the three commands are executed in succession by all slaves in this situation, set **1001** represents the A*~B+~A*B condition, set **1002**, the ~A*~B condition, and set **1003**, the A*B condition. As is, the slaves that satisfy the EXCLUSIVE-OR condition ended up in set **1001**. If the goal had been to place those slaves in set **1002** instead, a different sequence of commands would be broadcast. That sequence is shown in FIG. **19**. Rows **1900**, **1901**, **1902** and **1903** of the table show the initial and succeeding conditions obtained in each set during the execution of the sequence of commands T12(A), T23(B) and T12(B). If the goal had been to place the EXCLUSIVE-OR in set **1003** instead, a different sequence of commands would be broadcast. That sequence is shown in FIG. **20**. Rows **2000**, **2001**, **2002** and **2003** of the table show the initial and succeeding conditions obtained in each set during the execution of the sequence of commands T13(A), T32(B) and T13(B).

The present invention teaches several methods for generating a command sequence necessary to select slaves that satisfy an arbitrarily complex condition involving any number of primitive conditions. Before describing the most general methods, the invention first teaches a few important methods aimed at certain types of complex conditions. Non limiting examples of command sequences are given in the columns numbered **1810** (in FIG. **18**), **1910** (in FIG. **19**), **2010** (in FIG. **20**), **2610** (in FIG. **26**), **2710** (in FIG. **27**), **2910** (in FIG. **29**), **3010** (in FIG. **30**), **3210** (in FIG. **32**), **3310** (in FIG. **33**), **3510** (in FIG. **35**), **3610** (in FIG. **36**), **3910** (in FIG. **39**), and **4010** (in FIG. **40**).

Each command, T, sent from the master to one or more slaves, has a single primitive condition, ci, that is one of any number of arbitrary primitive conditions. The command, T, addresses some information stored on each of the slaves and causes the respective slave to compare its stored information with the primitive condition.

The first of those is a condition expressed by the product of two or more primitive conditions. This is the general AND condition and the method for handling that kind of condition is shown in FIG. **21**. Method **2100** takes as input **2101** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and an AND of N primitive conditions, that is c1*c2* . . . *cN. Method **2100** outputs a configuration **2102** whereby all slaves in set Ej that satisfied the aforementioned AND condition have moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in Ek that did not satisfy the reduced condition c2* . . . *cN have moved to set Ej. That can be represented mathematically as

$$Ej=Ej*\sim(c1*c2* \ldots *cN)+Ek*\sim(c2*c3* \ldots *cN)$$

$$Ek=Ej*(c1*c2* \ldots *cN)+Ek*(c2*c3* \ldots *cN)$$

Method **2100** accomplishes this by generating a sequence of N commands. In step **2110**, a command is issued that

causes all slaves in set Ej that satisfy first primitive condition c1 to move to set Ek. This command is written as Tjk(c1). The state transitions effected can be mathematically represented as

$$Ej=Ej*\sim C1$$

$$Ek=Ek+Ej*c1$$

Step **2120** controls the iteration over all remaining primitive conditions that make up the input AND condition **2101**. For each primitive condition ci, where i varies from 2 to N, step **2121** issues a command that causes all slaves in set Ek that do not satisfy primitive condition ci to move to set Ej. This command is written as Tkj(~ci). The state transitions effected can be mathematically represented as

$$Ej=Ej+Ek*\sim c1$$

$$Ek=Ek*c1$$

The iteration ends after the last primitive condition, cN, has been processed by step **2121**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2100** are exactly those that satisfy the AND condition.

The second is a condition expressed by the negation of a product of two or more primitive conditions. This is the general NAND condition and the method for handling that kind of condition is shown in FIG. **22**. Method **2200** takes an input **2201** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and a NAND of N primitive conditions, that is, ~(c1*c2* . . . *cN). Method **2200** outputs a configuration **2202** whereby all slaves in set Ej that satisfy the aforementioned NAND condition are moved to set Ek. That can be represented mathematically as

$$Ej=Ej*(c1*c2* \ldots *cN)$$

$$Ek=Ek+Ej*\sim(c1*c2* \ldots *cN)$$

Method **2200** accomplishes this by generating a sequence of N commands. The main step **2220** controls the iteration over all the primitive conditions that make up the input NAND condition. For each primitive condition ci, where i varies from 1 to N, step **2221** issues a command that causes all slaves in set Ej that do not satisfy primitive condition ci to move to set Ek. This command is written as Tjk(~ci). The state transitions effected can be mathematically represented as

$$Ej=Ej*c1$$

$$Ek=Ek+Ej*\sim c1$$

The iteration ends after the last primitive condition, cN, has been processed by step **2221**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2200** are exactly those that satisfy the NAND condition.

The third is a condition expressed by the sum of two or more primitive conditions. This is the general OR condition and the method for handling that kind of condition is shown in FIG. **23**. Method **2300** takes as input **2301** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and an OR of N primitive conditions, that is, c1+c2+. . . +cN. Method **2300** outputs a configuration **2302** whereby all slaves in set Ej that satisfy the aforementioned OR condition are moved to set Ek. That can be represented mathematically as

$$Ej=Ej*\sim(c1+c2+\ldots+cN)$$

$$Ej=Ek+Ej*(c1+c2+\ldots+cN)$$

Method **2300** accomplishes this by generating a sequence of N commands. The main step **2320** controls the iteration over all the primitive conditions that make up the input OR condition. For each primitive condition ci, where i varies from 1 to N, step **2321** issues a command that causes all slaves in set Ej that satisfy primitive condition ci to move to set Ek. This command is written as Tjk(ci). The state transitions effected can be mathematically represented as

$$Ej=Ej*\sim c1$$

$$Ek=Ek+Ej*c1$$

The iteration ends after the last primitive condition, cN, has been processed by step **2321**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2300** are exactly those that satisfy the OR condition.

The fourth is a condition expressed by the negation of the sum of two or more primitive conditions. This is the general NOR condition and the method for handling that kind of condition is shown in FIG. **24**. Method **2400** takes as input **2401** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and a NOR of N primitive conditions, that is, ~(c1+c2+. . . +cN). Method **2400** outputs a configuration **2402** whereby all slaves in set Ej that satisfy the aforementioned NOR condition are moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in Ek that satisfied the reduced condition c2+. . . +cN have moved to set Ej. That can be represented mathematically as

$$Ej=Ej*(c1+c2+\ldots+cN)+Ek*(c2+c3+\ldots+cN)$$

$$Ek=Ej*\sim(c1+c2+\ldots+cN)+Ek*\sim(c2+c3+\ldots+cN)$$

Method **2400** accomplishes this by generating a sequence of N commands. In step **2410**, a command is issued that causes all slaves in set Ej that do not satisfy first primitive condition c1 to move to set Ek. This command is written as Tjk(~c1). The state transitions effected can be mathematically represented as

$$Ej=Ej*c1$$

$$Ek=Ek+Ej*\sim c1$$

Step **2420** then controls the iteration over all the remaining primitive conditions that make up the input NOR condition. For each primitive condition ci, where i varies from 2 to N, step **2421** issues a command that causes all slaves in set Ek that satisfy primitive condition ci to move to set Ej. This command is written as Tkj(ci).

$$Ej=Ej+Ek*ci$$

$$Ek=Ek*\sim ci$$

The iterative step **2420** ends after the last primitive condition, cN, has been processed by step **2421**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2400** are exactly those that satisfy the NOR condition.

Methods **2100**, **2200**, **2300** and **2400** can be combined to handle arbitrarily complex conditions. The simplest such

combination is called canonical, because it is based on the well-known technique of expressing an arbitrarily complex condition in the form of sum-of-products, i.e., one or more ANDed primitive conditions that are ORed together. The canonical method works by computing each product term of the condition using two sets and accumulating, that is summing, the product terms into a third set.

FIG. **25** shows a method **2500** that moves slaves from the first to the second state and visa versa. When slaves are in the second state, it is possible to move them to the third state where all remaining commands in the command sequence are ignored. Method **2500** takes as input **2501** three different sets Ej, Ek, and El, that is, some permutation of sets **E1**, **E2** and **E3**, and a condition that is a sum of P product terms, that is, p1+p2+. . . +pP. Assuming, for simplicity, that set Ek is empty at the start of the method. Method **2500** outputs a configuration **2502** whereby all slaves in set Ej that satisfy the aforementioned sum-of-products condition are moved to set **E1**. That can be represented mathematically as

$$Ej=Ej*\sim(p1+p2+. . . +pP)$$

$$Ek=0$$

$$El=El+Ej*(p1+p2+. . . +pP)$$

Method **2500** accomplishes this by generating a sequence of commands. The main step **2520** controls the iteration over all the product terms that make up the input sum-of-products condition **2501**. For each product term pi, where i varies from 1 to P, first step **2421** issues a sequence of commands as defined by method **2100** that causes all slaves in set Ej that satisfy the product term pi to move to set Ek. Second step **2522** issues a command that causes all slaves in set Ek to move to set **E1**. The iteration ends after the last product term, pP, has been processed by steps **2521** and **2522**. That terminates the method.

In other words, the method **2500** creates each of the product terms in **2521** and in set Ek. After each product term, pi, is created, it is ORed with the previously accumulated product terms in set **E1**. That frees up set Ek in preparation for the next product term.

Applying the method **2500** to the EXCLUSIVE-OR condition ~A*B+A*~B, for example, results in the command sequence **2610** shown in FIG. **26**. The default initial configuration **2600** where all the slaves are in set **E1** is used. In this example, j=**1**, k=**2** and l=**3**. Commands T12(~A) and T21(~B), as per method **2100**, are used to move slaves that satisfy the product term ~A*B from set **E1** to set **E2**, as shown by rows **2601** and **2602**. Command T23(**1**) sums that product term from **E2** to **E3**, as shown in row **2603**. That is the basic cycle for one product term. Next, commands T12(A), T21(B) and T23(**1**) repeat the cycle to move slaves that satisfy the next product term A*~B first from set **E1** to set **E2** and second from set **E2** to set **E3**, as shown by rows **2604**, **2605** and **2606**. Six commands are generated by method **2500** for the EXCLUSIVE-OR condition, two of those on account of two product terms and the other four on account of four primitive conditions present over all product terms. Contrast this with the three commands generated by any the hand crafted solution of FIGS. **18**, **19** and **20**. While the canonical method is easy to compute, the command sequences it generates are not minimal in general.

An arbitrarily complex condition can be written in the form of a sum-of-products. A canonical method for generating a command sequence for a sum-of-products is to use first and second states to calculate product terms and to use the third state to accumulate the product terms. The canonical method does not yield the shortest command sequence but is easy to compute.

When a complex condition is put in sum-of-product form, the products do not have to be expanded so that each contains all primitive conditions used in the complex condition. For an example which includes three primitive conditions A, B, and C, the complex condition A*~B*C+A*B*C+~A*B*C+A*B*C can be minimized to A*C+B*C and still be considered a sum-of-products for the purpose of method **2500** and other methods described hereunder. Such a minimization represents a significant reduction in commands required. While the fully expanded condition above would require sixteen commands (four product terms and twelve primitive condition appearances), the corresponding minimized sum-of-products requires six commands (two product terms and four primitive condition appearances), when both the command sequences are generated through the canonical method **2500**. The six commands solution **2710** is shown in FIG. **27** and not surprisingly mimics the command sequence **2610** of FIG. **26**. Again a default initial configuration **2700** where all slaves are in set **E1** is used. In this example, j=**1**, k=**2** and l=**3**. Command T12(A) transfers from set **E1** to set **E2** the slaves in set **E1** that satisfy primitive condition A. Row **2701** indicates that set **E1** contains the slaves that satisfy condition ~A; set **E2**, condition A; and set **E3** is empty. Command T21(~C) transfers from set **E2** to set **E1** the slaves in set **E2** that do not satisfy primitive condition C. Row **2702** indicates that set **E1** represents condition ~A+A*~C, which is equivalent to ~A+~C; set **E2**, condition A*C; and set **E3** is empty. Command T23(l) transfers from set **E2** to set **E3** all slaves in set **E2**. Row **2703** indicates the accumulation of product term A*C into set **E3**. Command T12(B) transfers from set **E1** to set **E23** the slaves in set **E1** that satisfy primitive condition B. Row **2704** indicates that set **E1** represents the condition (~A+~C)*~B, which is equivalent to condition ~A*~B+~B*~C; and set **E2**, condition (~A+~C)*B, which is equivalent to ~A*B+B*~C. Command T21 (~C) transfers from set **E2** to set **E1** the slaves in set **E2** that do not satisfy primitive condition C. Row **2705** indicates that set **E1** represents condition ~A*~B+~B*~C+(~A*B+B*~C)*~C, which reduces to ~A*~B+~B*~C+~A*B*~C+B*~C, then to ~A*~B+~B*~C+B*~C, then to ~A*~B+~C; and set **E2** represents condition (~A*B+B*~C)*C, which is equivalent to ~A*B*C. Command T23(**1**) transfers from set **E2** to set **E3** all slaves in set **E2**. Row **2706** indicates that set **E3** represents the condition A*C+~A*B*C, which reduces to (A+~A*B)*C, then to (A+B)*C, then to A*C+B*C, which is the sum-of-product condition that needed to be satisfied. Applying method **2500** to a minimized sum-of-products, as in this example, will generate a command sequence that is certainly shorter than a full-expanded sum-of-products, but is still not necessarily minimal.

Characteristic of method **2500** is that the first set Ej serves as the main repository of slaves and will end up containing the slaves originally in set Ej that do not satisfy the sum-of-products condition. Second set Ek serves to build each product term. Third set **E1** serves to sum the product terms and will end up containing the slaves originally in set Ej that satisfy the sum-of-products condition. Therefore, for method **2500**, each of the three sets has a uniquely defined role.

This does not need to be the case and one can create variations of method **2500** where the roles alternate. The method shown in FIG. **28** is one such variation. Method **2800** differs from method **2500** in that the roles of states Ej (state **1**) and Ek (state **2**) alternate, i.e. states **1** and **2** reverse

roles. Product terms are build alternatively in states Ek and Ej: first in Ek, then in Ej, then back in Ek, and so on; in other words, odd product terms—first, third, fifth, etc.—are built in set Ek, while even product terms—second, fourth, sixth, etc.—are built in set Ej. Method **2800** is similar to method **2500** in that the role of state E1 remains the same. Method **2800** takes as input **2801** the same input as does method **2500**. Method **2800** takes as input **2801** the same input as does method **2500**. Method **2800** outputs a configuration whereby all slaves in Ej that satisfy the sum-of-products condition are moved to set E1, and either set Ej or Ek will be empty depending on the number of product terms. If the condition has an even number of product terms, Ek will be empty; otherwise, Ej will be empty. That can be represented mathematically as

$El=El+Ej*(p1+p2+. . . +pP)$

(if P is even) $Ej=Ej*\sim(p1+p2+. . . +pP)$

(if P is odd) $Ej=0$

(if P is even) $Ek=0$

(if P is odd) $Ek=Ej*\sim(p1+p2+. . . +pP)$

The main step **2820** controls the iteration over all the product terms that make up the sum-of-products condition **2801**. For each product term pi, where i varies from 1 to P, step **2830** tests whether i is odd or even. If i is odd, steps **2831** and **2833** are executed for product term pi. If i is even, steps **2832** and **2834** are executed for product term pi. Step **2831** issues a sequences of commands defined by NAND method **2200** that causes all slaves in set Ej that do not satisfy product term pi to move to set Ek. Step **2833** issues a command that causes all slaves in set Ej to move to set El. Similarly, step **2832** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set Ek that do not satisfy product term pi to move to set Ej. Step **2834** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last product term, pP, has been processed by either steps **2831** and **2833** (odd P case), or steps **2832** and **2834** (even P case). That terminates the method.

If method **2800** is used on the EXCLUSIVE-OR condition ~A*B+A*~B, the sequence of commands **2910** shown in FIG. **29** results. The default initial configuration **2900** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **2901** and **2902** correspond to the application of method **2200** from E1 to E2 to the product term ~A*B. Row **2903** is the accumulation of that product term in E3. Rows **2904** and **2905** correspond to the application of method **2200** from E2 to E1 to the product term A*~B. Row **2906** is the accumulation of that product term in E3. Because the number of product term is even in this case, E2 is empty at the end.

A similar sequence of commands results if method **2800** is used on the condition A*C+B*C. The sequence of commands **3010** is shown in FIG. **30**. The default initial configuration **3000** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3001** and **3002** correspond to the application of method **2200** from E1 to E2 to the product term A*C. Row **3003** is the accumulation of that product term in E3. Rows **3004** and **3005** correspond to the application of method **2200** from E2 to E1 to the product term B*C. Row **3006** is the accumulation of that product term in E3. Because the number of product term is even in this case, E2 is empty at the end.

The method shown in FIG. **31** differs from methods **2500** and **2800** in that both the building of product terms and the accumulation of product terms alternates between two sets. Specifically, the roles of set Ek (state 2) and E1 (state 3) reverse. With method **3100** product terms are either computed from set Ej to set Ek or from set Ej to set El. While for methods **2500** and **2800** summing was done by adding the latest product term into the previous accumulation, with method **3100** the previous accumulation is added to the latest product term. Accordingly, when the latest product term is built in set Ek, accumulation is from El to Ek, and when the latest product term is built in set El, accumulation is from Ek to El. Method **3100** takes as input **3101** the same input as do methods **2500** and **2800**. Method **3100** outputs a configuration whereby all slaves in Ej that satisfy the sum-of-products condition are moved to either set Ek or El depending on the number of product terms. If the condition has an even number of product terms, El will contains the desired slaves; otherwise, Ek will. That can be represented mathematically as

$Ej=Ej*\sim(p1+p2+. . . +pP)$

(if P is odd) $Ek=El+Ej*(p1+p2+. . . +pP)$

(if P is even) $Ek=0$

(if P is odd) $El=0$

(if P is even) $El=El+Ej*(p1+p2+. . . +pP)$

The main step **3120** controls the iteration over all the product terms that make up the sum-of-products condition **3101**. For each product term pi, where i varies from 1 to P, step **3130** tests whether i is odd or even. If i is odd, steps **3131** and **3133** are executed for product term pi. If i is even, steps **3132** and **3134** are executed for product term pi. Step **3131** issues a sequence of commands defined by AND method **2100** that causes all slaves in set Ej that satisfy product term pi to move to set Ek. Step **3133** issues a command that causes all slaves in set El to move to set Ek. Similarly, step **3132** issues a sequence of commands defined by AND method **2100** that causes all slaves in set Ej that satisfy product term pi to move to set El. Step **3134** issues a command that causes all slaves in set Ek to move to set El. The iterative step **3120** ends after the last product term, pP, has been processed by either steps **3131** and **3133** (odd P case), or steps **3132** and **3134** (even P case). That terminates the method.

If method **3100** is used on the EXCLUSIVE-OR condition ~A*B+A*~B, the sequence of commands **3210** shown in FIG. **32** results. The default initial configuration **3200** where all slaves are in set El is used. In this example j=1, k=2, and l=3. Rows **3201** and **3202** correspond to the application of method **2100** from E1 to E2 to the product term ~A*B. Row **3203** is the accumulation of E3 into that product term. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3204** and **3205** correspond to the application of method **2100** from E1 to E3 to the product term A*~B. Row **3206** is the accumulation of E2 into that product term. Because the number of product term is even in this case, E3 contains the desired set of slaves.

A similar sequence of commands results if method **3100** is used on the condition A*C+B*C. The sequence of commands **3310** is shown in FIG. **33**. The default initial configuration **3300** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3301** and **3302** correspond to the application of method **2100** from E1 to E2 to the product term A*C. Row **3303** is the accumulation of E3 into that product term. Because E3 is empty, this command is

unnecessary but is included as part of the normal cycle. Rows **3304** and **3305** correspond to the application of method **2100** from E1 to E3 to the product term B*C. Row **3306** is the accumulation of E2 into that product term. Because the number of product term is even in this case, E3 contains the desired set of slaves.

The method shown in FIG. **34** differs from methods **2500**, **2800** and **3100** in that the building of product terms and the accumulation of those products terms rotates among three sets, i.e., the states cycle roles. Method **3400** takes as input **3401** the same input as do methods **2500**, **2800** and **3100**. Method **3400** outputs a configuration whereby all slaves in set Ej that satisfy the sum-of-products condition are moved to set Ej, Ek or El depending on the number of product terms. If the number of product terms modulo **3** is one, that is, 1, 4, 7, etc., set Ej will end up containing the desired set of slaves. If the number of product terms modulo **3** is two, that is 2, 5, 8, etc., set Ek will end up containing the desired set of slaves. If the number of product terms modulo **3** is zero, that is, 3, 6, 9, etc., set E1 will end up containing the desired set of slaves. That can be represented mathematically as

(if (P mod **3**)=1) *Ej=El+p1+p2+. . . +pP, El=0*

(if (P mod **3**)=2) *Ek=El+p1+p2+. . . +pP, Ej=0*

(if (P mod **3**)=0) *El=El+p1+p2+. . . +pP, Ek=0*

The main step **3410** controls the iteration over all product terms that make up the sum-of-products condition **3401**. For each product term pi, where i varies from 1 to P, step **3420** tests whether i mod **3** is one, two or zero. If one, steps **3421** and **3424** are executed for product term pi. If two, steps **3422** and **3425** are executed for product term pi. If zero, steps **3423** and **3426** are executed for product term pi. Step **3421** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set Ej that do not satisfy product term pi to move to set Ek. Step **3424** issues a command that causes all slaves in set El to move to set Ej. Similarly, step **3422** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set Ek that do not satisfy product term pi to move to set El. Step **3425** issues a command that causes all slaves in set Ej to move to set Ek. Similarly, step **3423** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set E1 that do not satisfy product term pi to move to set Ej. Step **3426** issues a command that causes all slaves in set Ek to move to set El. The iterative step **3410** ends after the last product term, pP, has been processed. That terminates the method.

If method **3400** is used on the EXCLUSIVE-OR condition ~A*B+A*~B, the sequence of commands **3510** shown in FIG. **35** results. The default initial configuration **3500** where all slaves are in set El is used. In this example j=**32** 1, k=**2** and l=**3**. Rows **3501** and **3502** correspond to the application of method **2200** from E1 to E2 to the negated product term ~(~A*B). Row **3503** is the accumulation of E3 into E1. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3504** and **3505** correspond to the application of method **2200** from E2 to E3 to the negated product term ~A*~B). Row **3506** is the accumulation of E1 into E2. Because the number of product terms modulo three is two in this case, E2 contains the desired set of slaves.

A similar sequence of commands results if method **3500** is used on the condition A*C+B*C. The sequence of commands **3610** is shown in FIG. **36**. The default initial configuration **3600** where all slaves are in set E1 is used. In this example, j=1, k=**2** and l=**3**. Rows **3601** and **3602** correspond to the application of method **2200** from E1 to E2 to the negated product term ~(A*C). Row **3603** is the accumulation of E3 into E1. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3604** and **3605** correspond to the application of method **2200** from E2 to E3 to the negated product term ~(B*C). Row **3606** is the accumulation of E1 into E2. Because the number of product terms modulo three is two in this case, E2 contains the desired set of slaves.

Methods **2500**, **2800**, **3100** and **3400** do not in general generate a minimal sequence of commands for a given arbitrarily complex condition expressed in sum-of-products form. A shorter command sequence can be obtained when an arbitrarily complex condition can be written by an expression that can be generated by the following grammar:

ln-expression: (ln-expression)*primitive_condition

ln-expression: ln-expression+primitive_condition

ln-expression: primitive_condition

where ln-expression is the name given to this kind of expression, namely, left-nesting expression. A ln-expression can be written as, ((. . . (((c1) op2 c2) op3 c3) . . .) opN cN), where c1, c2, . . . , cN are primitive conditions and op2, op3, . . . , opN are either * (AND) or +(OR) binary operators. The ln-expression as written above is more heavily parenthetically bracketed than necessary and some parenthesis may be deleted as long as the logic is preserved. Left-nesting expressions can be executed using only two of the three states of the three-state machine. An arbitrarily complex condition such as A*B+A*C can be expressed according to the grammar as (B+C)*A. The aforementioned canonical method over the former, sum-of-products, expression requires six commands to execute and uses three states. The latter, left-nesting, expression can be computed with only three commands and uses only two states. Not every arbitrarily complex conditions can be expressed by a single left-nested expression, but any complex condition can be expressed by a sum of left-nested expressions, which requires fewer commands than the canonical sum-of-products form. For example, the condition A*B+A*C+ ~A*~B+~A*~C can be written as a sum of two left-nested expressions: (B+C)*A+(~B+~C)*~A; the former requires twelve commands, while the latter only eight. As with the canonical sum-of-products method, which uses the third state to accumulate products, the method for executing sum-of-left-nested-expressions uses the third state to accumulate left-nested expressions.

As mentioned above, the present three-selection-state machine is capable of isolating or selecting slaves that satisfy any possible condition expressed by a left-nested expression. Specifically, the invention is necessary and sufficient to isolate and select slaves satisfying those conditions that are expressed by a sum-of-left-nested-expressions. The invention enables this capability because a separate condition (or set of conditions), each corresponding to a set of slaves, can be isolated in any one of the three states at any given time. Therefore, operations on two sets of conditions, in two of the respective states, can be performed without affecting or being affected by the conditions held in the third state. Specific instances of left-nested-expressions handled by the invention are now presented.

The method for computing the sequence of commands necessary to transfer from a set Ej to a set Ek slaves in set

Ej that satisfy a condition given as a ln-expression is shown in FIG. **37**. Method **3700** takes as input **3701** two different sets Ej and Ek of the possible three sets E**1**, E**2** and E**3**, and a ln-expression, ((. . . (((c**1**) op**2** c**2**) op**3** c**3**) . . .) opN cN). Method **3700** outputs a configuration **3702** whereby all slaves in set Ej that satisfy the ln-expression of input **3701** are moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in set Ek that did not satisfy the reduced condition (. . . ((cM) op . . .) . . . opN cN)) where M is such that opM is the first * (AND) operator in the ln-expression, have moved to set Ej. That can be represented mathematically as

$$Ej=Ek^*\sim((cm\ op\ \ldots)opN\ cN)+Ej^*\sim(c1\ op\ \ldots)\ opN\ cN)$$

$$Ek=Ek^*\ ((cm\ op\ \ldots)\ opN\ cN)+Ej^*\ ((c1\ op\ \ldots)\ opN\ cN)$$

where m such that op**2**, op**3**, . . . , opm−**1**=OR and opm=AND

Method **3700** begins with step **3710**, which issues a command that causes all slaves in set Ej that satisfy the leftmost (first) primitive condition c**1** to move to set Ek. Step **3720** controls the iteration over the binary operators and attendant right operands, from the leftmost to the rightmost, that is, from op**2** to opN and their attendant c**2** to cN. For each operator opi, where i varies from 2 to N, step **3730** tests which binary operator is opi. If opi is the AND operator *, step **3731** is executed; otherwise, opi is the OR operator+, in which case step **3732** is executed. Step **3731** issues a command that causes all slaves in set Ek that do not satisfy primitive condition ci to move to set Ej. Step **3732** issues a command that causes all slaves in set Ej that satisfy primitive condition ci to move to set Ek. After the last iteration, over opN and cN, step **3720** terminates the iteration. That terminates the method.

An important variation of method **3700** is shown in FIG. **38**. Method **3800** computes the sequence of commands necessary to transfer from a set Ej to a set Ek slaves in set Ej that satisfy a condition given as the negation of a ln-expression. Method **3800** takes an input **3801** two different sets Ej and Ek of the possible three sets E**1**, E**2** and E**3**, and a condition in the form of a negated ln-expression, ~((. . . (((c**1**) op**2** c**2**) op**3** c**3**) . . .) opN cN). Method **3800** outputs a configuration **3802** whereby all slaves in set Ej that satisfy the negated ln-expression of input **3801** are moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in set Ek that did not satisfy the reduced condition ~(. . . ((cM) op . . .) . . . opN cN), where M is such that opM is the first+(OR) operator in the ln-expression, have moved to set Ej. That can be represented mathematically as

$$Ej=Ek^*((cm\ op\ \ldots)\ opN\ cN)+Ej^*\ ((cl\ op\ \ldots)\ opN\ cN)$$

$$Ek=Ek^*\sim((cm\ op\ \ldots)\ opN\ cN)+Ej^*\sim((cl\ op\ \ldots)\ opN\ cN)$$

where m such that op**2**, op**3**, . . . , opm−**1**=AND and opm=OR

Method **3800** begins with step **3810**, which issues a command that causes all slaves in set Ej that do not satisfy the leftmost (first) primitive condition c**1** to move to set Ek. Step **3820** controls the iteration over the binary operators and attendant right operands, from the leftmost to the rightmost, that is, from op**2** to opN and their attendant c**2** to cN. For each operator opi, where i varies from 2 to N, step **3830** tests which binary operator is opi. If opi is the OR operator +, step **3831** is executed; otherwise, opi is the AND operator *, in which case step **3832** is executed. Step **3831** issues a command that causes all slaves in set Ek that satisfy primitive condition ci to move to set Ej. Step **3832** issues a command that causes all slaves in set Ej that do not satisfy primitive condition ci to move to set Ek. After the last iteration, over opN and cN, step **3820** terminates. That terminates the method.

By expressing the minimized sum-of-products condition A*C+B*C, used in previous examples, as an ln-expression (A+B)*C, either method **3700** or **3800** can be used to generate a sequence of commands that is shorter than the sequence generated by method **2500**, **2800**, **3100** or **3400**. The latter sequence is six commands long, as shown in FIGS. **27**, **30**, **33**, and **36**. Both methods **3700** and **3800** generate a sequence that is three commands long. The example sequence **3910** generated by method **3700** is shown in FIG. **39**. The example sequence **4010** generated by method **3800** is shown in FIG. **40**. They both start with the default initial configuration where all slaves are in set E**1**, as shown in rows **3900** and **4000**. In both examples j=**1**, k=**2** and l=**3**. Method **3700** generates the sequence T**12**(A), T**12**(B) and T**21**(~C). Commands T**12**(A) and T**12**(B) put the partial condition (A+B) in set E**2** as shown in rows **3901** and **3902**. Command T**21**(~C) results in the desired condition (A+B)*C in set E**2** as shown in row **3903**. Method **3800** generates the sequence T**12**(~A), T**21**(B) and T**12**(~C). Commands T**12**(~A) and T**21**(B) put the partial condition (A+B) in set E**1** as shown in rows **4001** and **4002**. Command T**12**(~C) results in the desired condition (A+B)*C in set E**1** as shown in row **4003**.

Note from the method descriptions of FIGS. **37** and **38**, and the examples of FIGS. **39** and **40**, that the third set E**3** is not used. It is an important property of conditions written as a single ln-expression, that they require only two of the three states of a three-state machine. This property permits the use of the third state, that is, of set E**3**, as an accumulator of ln-expressions. While not all arbitrarily complex conditions can be expressed by a single ln-expression, any arbitrary complex condition can be expressed by a sum-of-ln-expressions. It is possible therefore to recode methods **2500**, **2800**, **3100** and **3400** to work on sum-on-ln-expressions.

Method **2500** is recoded in FIG. **41** for sum-of-ln-expressions. Method **4100** takes an input **4101** three sets Ej, Ek and El, that is, some permutation of sets E**1**, E**2** and E**3**, and a condition written as a sum-of-ln-expressions, n**1**+n**2**+. . . +nN. Assuming, for simplicity, that set Ek is empty at the start of the method. Method **4100** outputs a configuration **4102** whereby all slaves in set Ej that satisfy the sum-of-ln-expressions condition **4101** are moved to set E**1**. That can be represented mathematically as

$$Ej=Ej^*\sim(n1+n2+\ldots+nN)$$

$$Ek=0$$

$$El=El+Ej^*(n1+n2+\ldots+nN)$$

The main step **4120** controls the iteration over all ln-expressions of condition **4101**. For each ln-expression ni, where i varies from 1 to N, steps **4121** and **4122** are executed in that order. Step **4121** issues a sequence of commands defined by method **3700** that causes all slaves in set Ej that satisfy the ln-expression ni to move to set Ek. Step **4122** issues a command that causes all slaves in set Ek to move to set El. Iteration ends after the last ln-expression, nN, has been processed. That terminates the method.

Method **2800** is recoded in FIG. **42** for sum-of-ln-expressions. Method **4200** takes as input **4201** the same input as does method **4100**. Method **4200** outputs a con-

figuration **4202** whereby all slaves in Ej that satisfy the sum-of-ln-expressions condition **4201** are moved to set El, and either set Ej or set Ek will be empty depending on the number of ln-expressions. If the condition has an even number of ln-expressions, set Ek will be empty; otherwise, set Ej will be empty. That can be represented mathematically as

$$El=El+Ej^*(n1+n2+\ldots+nN)$$

(if N is even) $Ej=Ej^*\sim(n1+n2+\ldots+nN), Ek=0$

(if N is odd) $Ek=Ej^*\sim(n1+n2+\ldots+nN), Ej=0$

The main step **4220** controls the iteration over all ln-expressions of condition **4201**. For each ln-expression ni, where i varies from 1 to N, step **4230** tests whether i is odd or even. If i is odd, steps **4231** and **4233** are executed for ln-expression ni. If i is even, steps **4232** and **4234** are executed for ln-expression ni. Step **4231** issues a sequence of commands defined by method **3800** that causes all slaves in set Ej that do not satisfy ln-expression ni to move to set Ek. Step **4233** issues a command that causes all slaves in set Ej to move to set El. Similarly, step **4232** issues a sequence of commands defined by method **3800** that causes all slaves in set Ek that do not satisfy ln-expression ni to move to set Ej. Step **4234** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last ln-expression, nP, has been processed by either steps **4231** and **4233**, or steps **4232** and **4234**. That terminates the method.

Method **3100** is recoded in FIG. **43** for sum-of-ln-expressions. Method **4300** takes as input **4301** the same input as do methods **4100** and **4200**. Method **4300** outputs a configuration **4302** whereby all slaves in set Ej that satisfy the sum-of-ln-expressions condition **4301** are moved to either set Ek or set El depending on the number of ln-expressions. If the condition has an even number of ln-expressions, set El will contain the desired slaves; otherwise, set Ek will. That can be represented mathematically as

$$Ej=Ej^*\sim(n1+n2+\ldots+nN)$$

(if N is odd) $Ek=El+Ej^*(n1+n2+\ldots+nN), El=0$

(if N is even) $El=El+Ej^*(n1+n2+\ldots+nN), Ek=0$

The main step **4320** controls the iteration over all ln-expressions of condition **4301**. For each ln-expression ni, where i varies from 1 to N, step **4330** tests whether i is odd or even. If i is odd, steps **4331** and **4333** are executed for ln-expression ni. If i is even, steps **4332** and **4334** are executed for ln-expression ni. Step **4331** issues a sequence of commands defined by method **3700** that causes all slaves in set Ej that satisfy ln-expression ni to move to set Ek. Step **4333** issues a command that causes all slaves in set El to move to set Ek. Similarly, step **4332** issues a sequence of commands defined by method **3700** that causes all slaves in set Ej that satisfy ln-expression ni to move to set El. Step **4334** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last ln-expression, nN, is processed. That terminates the method.

Method **3400** is recoded in FIG. **44** for sum-of-ln-expressions. Method **4400** takes as input **4401** the same input as do methods **4100**, **4200** and **4300**. Method **4400** outputs a configuration **4402** whereby all slaves in set Ej that satisfy the sum-of-ln-expressions condition **4401** are moved to set Ej, Ek or El depending on the number of ln-expressions. If the number of ln-expressions modulo three is one, that is, 1, 4, 7, etc., set Ej will end up containing the desired set of slaves. If the number of ln-expressions modulo three is two, that, 2, 5, 8, etc., set Ek will end up containing the desired set of slaves. If the number of ln-expressions modulo three is zero, that is, 3, 6, 9, etc., set El will end up containing the desired set of slaves. That can be represented mathematically as

(if (N mod **3**)=1) $Ej=El+Ej^*(n1+n2+\ldots+nN), El=0$

(if (N mod **3**)=2) $Ek=El+Ej^*(n1+n2+\ldots+nN), Ej=0$

(if (N mod **3**)=0) $El=El+Ej^*(n1+n2+\ldots+nN), Ek=0$

The main step **4410** controls the iteration over all ln-expressions of condition **4401**. For each ln-expression ni, where i varies from 1 to N, steps **4419** and **4420** test whether i mod **3** is one, two or zero. If one, steps **4421** and **4424** are executed for ln-expression ni. If two, steps **4422** and **4425** are executed for ln-expression ni. If zero, steps **4423** and **4426** are executed for ln-expression ni. Step **4421** issues a sequence of commands defined by method **3800** that causes all slaves in set Ej that do not satisfy ln-expression ni to move to set Ek. Step **4424** issues a command that causes all slaves in set El to move to set Ej. Similarly, step **4422** issues a sequence of commands defined by method **3800** that causes all slaves in set Ek that do not satisfy ln-expression ni to move to set El. Step **4425** issues a command that causes all slaves in set Ej to move to set Ek. Similarly, step **4423** issues a sequence of commands defined by method **3800** that causes all slaves in set El that do not satisfy ln-expression ni to move to set Ej. Step **4426** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last ln-expression, nN, is processed. That terminates the method.

For example, the condition A*B+A*C+~A*~C, which would require ten commands if handled by any of methods **2500**, **2800**, **3100** or **3400**, can be rewritten as (B+C)*A+~A*~B*~C and handled by any of methods **4100**, **4200**, **4300** and **4400**, in which case only eight commands are necessary. In the particular case of method **4100** the eight commands are T12(B), T12(C), T21(~A), T23(1), T12(~A), T21(B), T21(C), and T23(l).

As evident by the examples and method descriptions, not all possible transitions of the three-state machine need be available. Methods **2500** and **4100** can be executed on any of three-state machines **400**, **500**, **600**, or **700**. Methods **2800** and **4200** can be executed on any of three-state machines **400** or **500**. Methods **3100** and **4300** can be executed on any of three-state machines **400** or **500**. Methods **3400** and **4400** can be executed on any of three-state machines **400**, **500**, **600** and **800**. Therefore for three-state machines **400** and **500**, methods **2500**, **2800**, **3100**, **3400**, **4100**, **4200**, **4300** and **4400** can be used singly or in combination. For three-state machine **600**, methods **2500**, **3400**, **4100** and **4400** can be used singly or in combination. For three-state machine **700**, only methods **2500** and **4100** can be used singly or in combination. For three-state machine **800**, only methods **3400** and **4400** can be used singly or in combination.

Other state machines are possible as long as any of three-state machines **400**, **500**, **600**, **700** or **800** remains a corner- stone of the architecture. More states may be added and different transition combinations can be used, any of which could be realized by those skilled in the art given the disclosure presented herein, and depending upon the particular specifications desired. Moreover concomitant varia-

tions in the methods herein described and the form by which conditions are expressed and input to the methods will immediately become apparent to those skilled in the art. For example, iteration over elements of an ln-expression could be handled through recursion instead. They can utilize the teachings of this disclosure to create efficient operative embodiments of the system and methods described and claimed. These embodiments are also within the contemplation of the inventor.

I claim:

1. A state machine slave comprising:

three or more states, being at least a first state, a second state, and a third state, the slave being in the first state;

a memory with one or more information values;

a receiving unit for receiving one or more commands in a command sequence, each of the commands specifying a "transfer from state", a "transfer to state", and a primitive condition; and

a processing unit that causes the slave to move to the second state being the "transfer to state" if the first state is the same as the "transfer from state" and one or more of the information values satisfies the primitive condition, the slave being moved to the third state by another command in the command sequence only if the slave is in the second state, and the slave, once moved into to the third state, remaining in the third state,

wherein two of the states reverse roles after an end of one or more subsequences in the sequence of commands.

2. A state machine slave, as in claim **1**, wherein said at least two of the three states exchange roles with each other after an end of one or more subsequences in the sequence of commands as follows: the first and second states reverse roles.

3. A state machine slave, as in claim **2**, where the first and second states reverse roles at the end of each subsequence corresponding to a term in a sum of ln-expression.

4. A state machine slave, as in claim **3**, where the sum of ln-expression is a sum of products.

5. A state machine slave, as in claim **1**, wherein said at least two of the three states exchange roles with each other after an end of one or more subsequences in the sequence of commands as follows: the second and third states reverse roles.

6. A state machine slave, as in claim **5**, where the second and third states reverse roles at the end of each subsequence corresponding to a term in a sum of ln-expression.

7. A state machine slave, as in claim **6**, where the sum of ln-expression is a sum of products.

8. A state machine slave, as in claim **1**, wherein said at least two of the three states exchange roles with each other after an end of one or more subsequences in the sequence of commands as follows: the first state assumes the role of the second state, the second state assumes the role of the third state, and the third state assumes the role of the first state.

9. A state machine slave, as in claim **8**, where the first, second, and third states cycle roles at the end of each subsequence corresponding to a term in a sum of ln-expression.

10. A state machine slave, as in claim **9**, where the sum of ln-expression is a sum of products.

11. A system for selecting a subset of slaves that satisfy a selection criterion, comprising:

a master unit for communicating a selection criterion command sequence to a plurality of slaves, the selection criterion command sequence representing the selection criterion;

each slave of said plurality of slaves at any time being in one of three or more different possible selection states, said states being used for processing the selection criterion command sequence and for determining whether or not said each slave satisfies the selection criterion represented by the selection criterion command sequence;

a memory in said each slave containing at least one information value for evaluation of primitive selection conditions;

a receiving unit in said each slave for receiving the selection criterion command sequence from the master unit, each command in the selection criterion command sequence specifying a "from" state, a "to" state, and a primitive selection condition; and

a processing unit in said each slave that processes each successive command in the selection criterion command sequence by moving the slave into the "to" state if and only if the slave is already in the "from" state and the at least one information value satisfies the primitive condition,

whereby said each slave is deemed to be selected if said each slave is in a particular selection state after the processing unit in said each slave has processed the selection criterion command sequence.

12. A system, as in claim **11**, where the master unit is a base station, the slaves are radio frequency tags, and the base station communicates with the radio frequency tags with a radio frequency signal.

13. A system, as in claim **11**, where the selection criterion command sequence moves one or more first sets of slaves from a first state to a second state, then moves one or more second sets of slaves from the second state to the first state, and then moves the slaves remaining in the second state to a third state.

14. A system, as in claim **11**, where the selection criterion command sequence moves one or more first sets of slaves from a first state to a second state, then moves one or more second sets of slaves from the second state to the first state, and then moves the slaves remaining in the first state to a third state.

15. A system, as in claim **11**, where the selection criterion command sequence moves one or more first sets of slaves from a first state to a second state and then moves one or more second sets of slaves from the second state to a third state.

16. A system, as in claim **11**, where the selection criterion command sequence moves one or more first sets of slaves from a first state to a second state and then moves one or more second sets of slaves from the first state to a third state.

17. A method for selecting a subset of slaves that satisfy a selection criterion, comprising the steps of:

storing at least one information value in each of a plurality of slaves for evaluating primitive selection conditions;

representing a selection criterion as a selection criterion command sequence, each command in the selection criterion command sequence specifying a "from"state, a "to" state, and a primitive selection condition;

communicating the selection criterion command sequence to the plurality of slaves, each slave of said plurality of slaves at any time being in one of three or more different selection states used for processing the selection criterion command sequence and for determining whether or not said each slave satisfies the selection criterion represented by the selection criterion command sequence;

processing each successive command in the selection criterion command sequence at said each slave by moving said each slave into the "to" state if and only if the slave is already in the "from" state and the at least one information value satisfies the primitive condition; and then

deeming said each slave in a particular selection state to be selected.

18. A state machine slave for responding to a selection criterion command sequence from a master unit, the selection criterion command sequence implementing a selection criterion, the state machine slave comprising:

first, second and third selection states for processing the selection criterion command sequence and for determining whether or not the slave satisfies the selection criterion represented by the selection criterion command sequence;

a memory containing at least one information value for evaluating primitive selection conditions;

a receiving unit for receiving the selection criterion command sequence, each command in the selection criterion command sequence specifying a "from" state, a "to" state, and a primitive selection condition; and

a processing unit that process each successive command in the selection criterion command sequence by moving the slave into the "to" state if and only if the slave is already in the "from" state and the at least one information value satisfies the primitive condition,

whereby the slave is deemed to be selected if the slave is in a particular one of the three states after the processing unit has processed the selection criterion command sequence.

* * * * *

EXHIBIT D

US005850181A

United States Patent [19]

Heinrich et al.

[11] **Patent Number: 5,850,181**

[45] **Date of Patent: Dec. 15, 1998**

[54] **METHOD OF TRANSPORTING RADIO FREQUENCY POWER TO ENERGIZE RADIO FREQUENCY IDENTIFICATION TRANSPONDERS**

[75] Inventors: **Harley Kent Heinrich**, Brewster; **Rene Dominic Martinez**, Putman Valley, both of N.Y.; **Paul Jorge Sousa**, Middleton, Mass.; **Li-Cheng Richard Zai**, Ossining, N.Y.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **626,820**

[22] Filed: **Apr. 3, 1996**

[51] **Int. Cl.**[6] **G08B 13/14**

[52] **U.S. Cl.** **340/572**; 340/693

[58] **Field of Search** 340/572, 825.54, 340/825.69, 693; 342/42, 44, 51; 375/202

[56] **References Cited**

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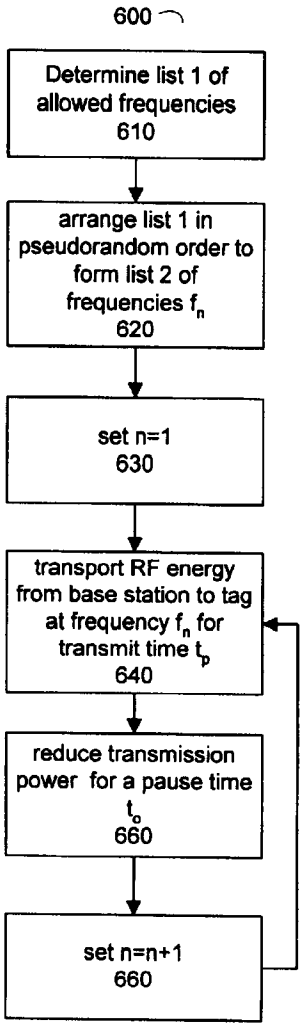
Primary Examiner—Thomas J. Mullen, Jr.
Attorney, Agent, or Firm—Rodney T. Hodgson

[57] **ABSTRACT**

An apparatus and a method of transporting energy from a base station to energize a remote RF transponder having an energy store is described, comprising transporting power in pulses of frequencies chosen from a randomly ordered list of frequencies, wherein the time between pulses when little power is transmitted is less than the time taken for the remote transponder to deplete the energy store.

30 Claims, 2 Drawing Sheets



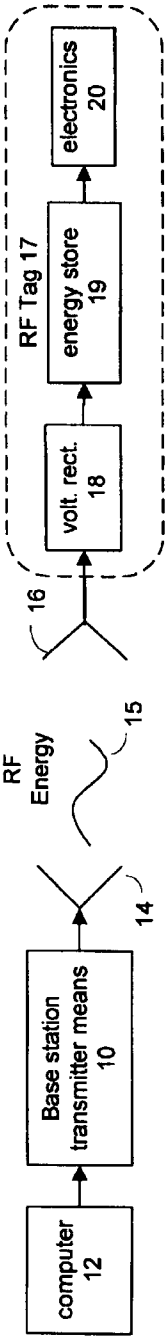


Fig. 1

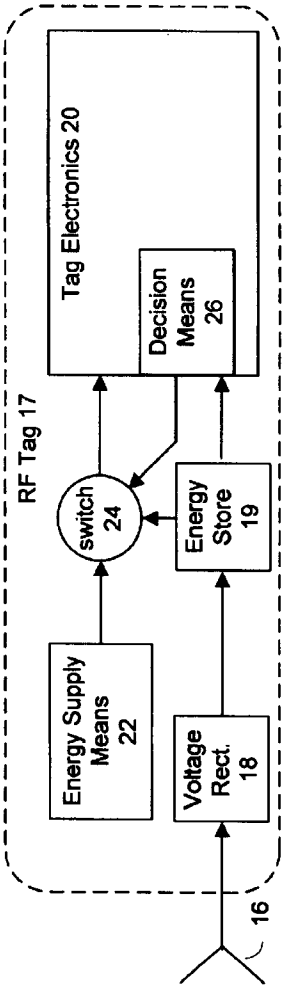


Fig. 2

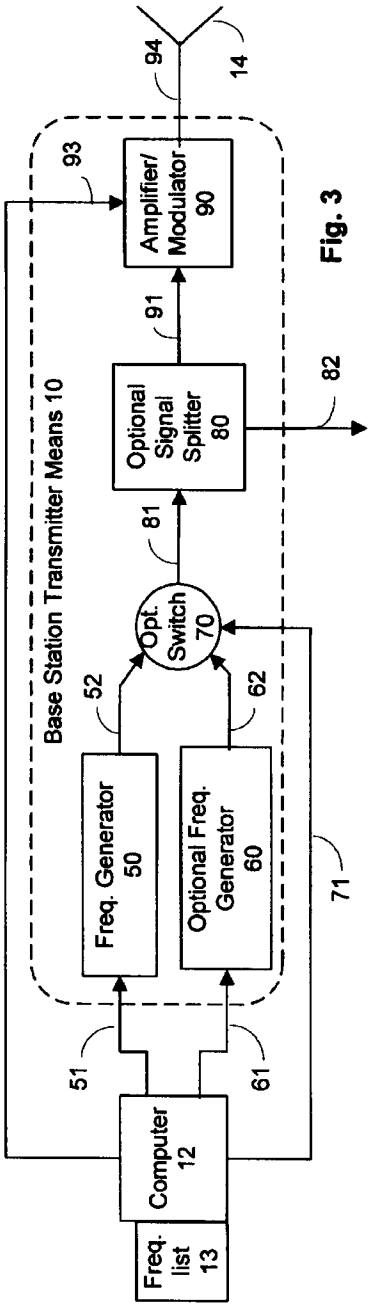


Fig. 3

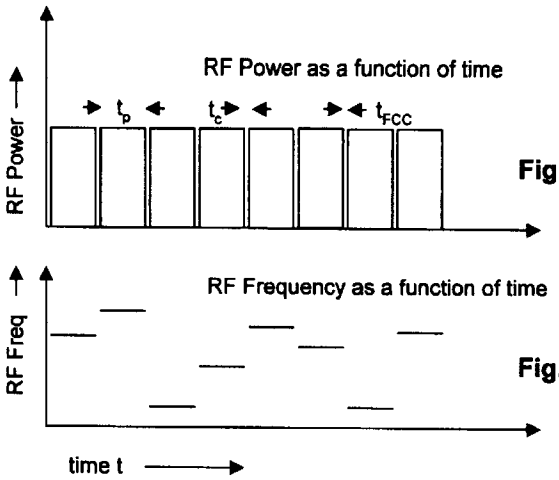


Fig. 4a

Fig. 4b

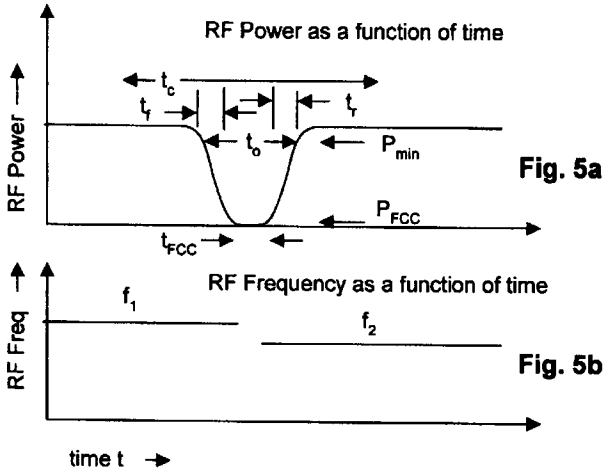


Fig. 5a

Fig. 5b

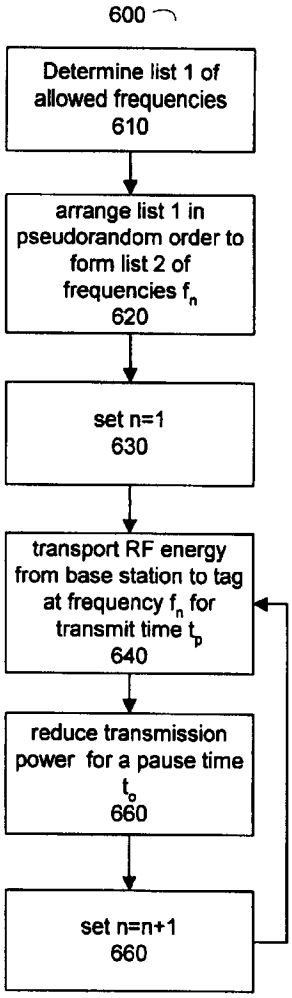


Fig. 6

METHOD OF TRANSPORTING RADIO FREQUENCY POWER TO ENERGIZE RADIO FREQUENCY IDENTIFICATION TRANSPONDERS

RELATED PATENT APPLICATIONS

Patent applications assigned to the assignee of the present invention: Ser. No. 08/303,965 filed Sep. 9, 1994 entitled "System and Method for Radio Frequency Tag Group Select", by Cesar et al.(now U.S. Pat. No. 5,673,037 issued Sep. 30, 1997); Ser. No. 08/304,340 filed Sep. 9, 1994 entitled Multiple Item Radio Frequency Tag Identification Protocol", by Chan et al., (now U.S. Pat. No. 5,550,547 issued Aug. 27, 1996); and Ser. No. 08/621,784, filed on Mar. 25, 1996 entitled "Thin Radio Frequency Transponder with Lead Frame Antenna Structure" by Brady et al. (pending) are hereby incorporated by reference.

BACKGROUND OF THE INVENTION 1. Field of the invention.

The field of the invention is the field of Radio Frequency (RF) transmission of power to supply energy to remote electronic equipment, especially equipment for the location, identification, and measurement of objects, items, animals, or people associated with RF transponders.

2. Description of the prior art.

RF Transponders (RF Tags) can be used in a multiplicity of ways for locating and identifying accompanying objects and transmitting information about the state of the object. It has been known since the early 60's in U.S. Pat. No. 3,098,971 by R.M. Richardson, that electronic components of transponders could be powered by radio frequency (RF) electromagnetic (EM) waves sent by a "base station" and received by a tag antenna on the transponder. The RF EM field induces an alternating current in the transponder antenna which can be rectified by an RF diode on the transponder, and the rectified current can be used for a power supply for the electronic components of the transponder. The transponder antenna loading is changed by something that was to be measured, for example a microphone resistance in the cited patent. The oscillating current induced in the transponder antenna from the incoming RF energy would thus be changed, and the change in the oscillating current led to a change in the RF power radiated from the transponder antenna. This change in the radiated power from the transponder antenna could be picked up by the base station antenna and thus the microphone would in effect broadcast power without itself having a self contained power supply. The "rebroadcast" of the incoming RF energy is conventionally called "back scattering", even though the transponder broadcasts the energy in a pattern determined solely by the transponder antenna. Since this type of transponder carries no power supply of its own, it is called a "passive" transponder to distinguish it from a transponder containing a battery or other energy supply, conventionally called an active transponder.

Active transponders with batteries or other independent energy storage and supply means such as fuel cells, solar cells, radioactive energy sources etc. can carry enough energy to energize logic, memory, and tag antenna control circuits. However, the usual problems with life and expense limit the usefulness of such transponders.

In the 70's, suggestions to use backscatter transponders with memories were made. In this way, the transponder could not only be used to measure some characteristic, for example the temperature of an animal in U.S. Pat. No. 4,075,632 to Baldwin et. al., but could also identify the animal.

The continuing march of semiconductor technology to smaller, faster, and less power hungry has allowed enormous increases of function and enormous drop of cost of such transponders. Presently available research and development technology will also allow new function and different products in communications technology. However, the new functions allowed and desired consume more and more power, even though the individual components consume less power.

It is thus of increasing importance to be able to power the transponders adequately and increase the range which at which they can be used. One method of powering the transponders suggested is to send information back and forth to the transponder using normal RF techniques and to transport power by some means other than the RF power at the communications frequency. However, such means require use of possibly two tag antennas or more complicated electronics.

Sending a swept frequency to a transponder was suggested in U.S. Pat. No. 3,774,205. The transponder would have elements resonant at different frequencies connected to the tag antenna, so that when the frequency swept over one of the resonances, the tag antenna response would change, and the backscattered signal could be picked up and the resonance pattern detected.

Prior art systems can interrogate the tags if more than one tag is in the field. U.S. Pat. No. 5,214,410, hereby incorporated by reference, teaches a method for a base station to communicate with a plurality of tags .

Sending at least two frequencies from at least two antennas to avoid the "dead spots" caused by reflection of the RF was proposed in EPO 598 624 A1, by Marsh et al. The two frequencies would be transmitted simultaneously, so that a transponder in the "dead spot" of one frequency would never be without power and lose its memory of the preceding transaction.

The prior art teaches a method to interrogate a plurality of tags in the field of the base station. The tags are energized, and send a response signal at random times. If the base station can read a tag unimpeded by signals from other tags, the base station interrupts the interrogation signal, and the tag which is sending and has been identified, shuts down. The process continues until all tags in the field have been identified. If the number of possible tags in the field is large, this process can take a very long time. The average time between the random responses of the tags must be set very long so that there is a reasonable probability that a tag can communicate in a time window free of interference from the other tags.

In order that the prior art methods of communicating with a multiplicity of tags can be carried out, it is important that the tags continue to receive power for the tag electronics during the entire communication period. If the power reception is interrupted for a length of time which exceeds the energy storage time of the tag power supply, the tag "loses" the memory that it was turned off from communication, and will restart trying to communicate with the base station, and interfere with the orderly communication between the base station and the multiplicity of tags.

The amount of power that can be broadcast in each RF band is severely limited by law and regulation to avoid interference between two users of the electromagnetic spectrum. For some particular RF bands, there are two limits on the power radiated. One limit is a limit on the continuously radiated power in a particular bandwidth, and another limit is a limit on peak power. The amount of power that can be pulsed in a particular frequency band for a short time is much higher than that which can be broadcast continuously.

Federal Communications Commission Regulation 15.247 and 15.249 of Apr. 25, 1989 (47 C.F.R. 15.247 and 15.249) regulates the communications transmissions on bands 902–928 MHZ, 2400–2483.5 MHZ, and 5725–5850 MHZ. In this section, intentional communications transmitters are allowed to communicate to a receiver by frequently changing frequencies on both the transmitter and the receiver in synchronism or by "spreading out" the power over a broader bandwidth. The receiver is, however, required to change the reception frequency in synchronism with the transmitter.

OBJECTS OF THE INVENTION

It is an object of the invention to provide an improved system, apparatus, and method to transport RF power to an RF transponder.

It is further a object of the invention to transport RF power to an RF transponder which contains an independent power means in order to "switch on" the independent power means.

SUMMARY OF THE INVENTION

The present invention is an apparatus, a system, and a method to use a "hopping frequency" signal to power remote electronic equipment such as RF transponders. In essence, an RF transmitter broadcasts a series of high power pulses, where the frequency of each pulse is chosen in order from a pseudo randomly ordered list of allowed frequencies. The transponders are able to receive power at all the frequencies sent. The energy received is stored in an energy store on the tag.

The time between pulses must be shorter than the time taken for the tag electronics to deplete the energy store on the tag.

The transponder could be passive or active, and the power transported to an active transponder could be used to activate a switching means to switch on the active power source when the transponder is in the range of the base station transmitter, and thus save the battery energy which would not be needed to "listen for" the communications when the transponder was not in the range of the transmitter of the base station.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for transporting RF power to an RF transponder.

FIG. **2** is a block diagram of an RF transponder having an independent power means and a switching means for switching on the independent power means when the switching means is energized by the transported RF power or, alternatively, when a part of the tag electronics is energized by the transported RF power.

FIG. **3** is block diagram of an alternative preferred apparatus of the invention.

FIG. **4***a* is the power and FIG. **4***b* is the frequency transmitted as a function of time in one of the preferred methods of the invention.

FIG. **5***a* is the power and fig. **5***b* is the frequency transmitted as a function of time in one of the preferred methods of the invention.

FIG. **6** is a block diagram of an alternative preferred method of the invention.

DETAILED DESCRIPTION OF THE INVENTION

A method of transporting power to a remote antenna connected to electronic circuitry for the purpose of energizing the electronic circuitry is proposed. A preferred embodiment is to transport power to an RF Identification and Location transponder (RFID Transponder) having logic circuits, memory circuits, and antenna impedance control circuits. The memory circuits can be written and read remotely. Examples of preferred RFID transponders and base stations are given in U.S. Pat. No. 4,656,463 issued on Apr. 7, 1987 by Anders et. al., which patent is hereby incorporated by reference.

FIG. **1** is a block diagram outlining the apparatus needed for implementing the method of the invention. A base station transmitter **10** is controlled by computer means **12** to send various frequencies and amplitudes of RF energy to base station antenna **14**. Antenna **14** radiates an RF electromagnetic wave **15** which causes a current to oscillate in tag antenna **16** of the transponder (tag) **17** receiving the RF power. A voltage rectifying power circuit **18** connected to tag antenna **16** provides power to energy store **19** while the RF energy **15** is being broadcast. Energy store **19** can be any means known in the art for storing energy, but is typically a capacitor on a semiconductor chip. Energy store **19** supplies energy to the electronic circuitry **20**. Electronic circuitry **20** may contain communication circuitry for receiving communications sent from the base station in the form of modulations of the RF energy and/or frequency. Electronic circuitry **20** may contain a read only memory and/or a read write memory and/or a means for changing the loading on the tag antenna in order to change the back scattering characteristics of the tag antenna for purposes of communication with the base station. Computer **12** may also be used to receive, analyze, store, and communicate data sent by the base station transmitter **10** to the transponder. Computer **12** may also receive and communicate data sent by the tag to a receiver (not shown). The tag requires both power to operate, and a minimum voltage to run the semiconductor devices in the tag electronics **20**. It is important that the voltage supplied by the tag energy store **19** not drop below a threshold level during the tag communication protocol. If the RF energy **15** transmitted from the base station antenna **14** is stopped, the energy stored in the tag energy store **19** is depleted in a characteristic time t. which depends on the capacity of the tag energy store **19**, the amount of energy actually stored in the tag energy store **19**, (since the tag may be in a range from the base station where the energy store is not fully charged) and the power demands of circuitry **20**. The capacity of the tag energy store can be made quite large, but for low cost tags, it should be in the range of the energy storage capacitance of capacitors formed by normal electronics technology used for semiconductor chips. More capacitance takes more area on the chip, and is more costly. It is necessary that the RF transmission of energy not be interrupted for a time to greater than the critical time t_c. It is preferable that the RF transmission of energy be interrupted for a time t_o less than 400 milliseconds. It is more preferable that the transmission be interrupted for a time t_o less than 400 microseconds, even more preferable that the transmission be interrupted for a time t_o less than 50 microseconds, and most preferable that the transmission be interrupted for a time t_o less than 30 microseconds. (See discussion of FIG. **5** below),

FIG. **2** shows a block diagram of the apparatus for implementing a preferred method of the invention where the tag **17** is an active tag which contains an energy supply means **22** such as a battery and a switch means **24** for connecting the energy supply means **22** to the tag electronics **20** when the switch means **24** is energized by the voltage rectifying power circuit **18** and the energy store **19**. Elec-

tronic circuitry decision means **26** which is part of the tag electronics **20** may alternatively be energized by the voltage rectifying power circuit **18**, and decision means **26** may decide on the basis of the power received by the energy supply means **22** to fully energize electronic circuitry **20** by connecting energy supply means **22** with the tag electronics through switch means **24**.

In one preferred method of the invention, the frequency sent out from the base station must be changed over time. However, if the frequency is changed slowly from a first frequency f_1 to a second frequency f_2, the sent out frequency passes through a number of other frequencies in between f_1 and f_2. If the frequency is changed very rapidly, a large bandwidth of frequencies is generated, with the bandwidth center sweeping from f_1 to f_2 over time. Both of these results would result in possible interference with other users of the spectrum, which is prohibited by FCC regulations. A preferred method is to turn off the transmitter or reduce the power of the transmitter while the frequency change is taking place.

However, the tag relies on the sent out power to keep critical functions, such as its "short term memory", active while the tag and the base station are in communication with each other. Other critical functions of the tag which would be affected by loss of power are the "clock signal" which would be lost and a "tag state" which would be changed. Loss of the "short term memory" would seriously affect communication protocols for the tag, IE. the multiple tag communication protocols referred to above. It is critical that the power be turned off for a very short time.

A base station transmitter **10** for transporting RF power to RF transponders shown in FIG. **3** enables sending out two different frequency pulses separated by a very short time, specifically less than t_c. In one embodiment, a single RF generator **50** is used to sequentially generate two different RF frequencies f_1 and f_2 under control of the computer **12** over line **51**. RF generator **50** can switch frequencies in a time less than the time t_c which is taken for the tag energy store **19** to be drained to a level where a critical tag function is impaired. When RF generator **50** is switching frequency, amplifier/modulator unit **90** is switched off under control of computer **12** over line **93**. RF generators **50** (and **60**) and RF amplifier/modulators are well known.

In another preferred embodiment, one or more additional optional RF generators **60** are included in the base station transmitter means **10**. This is an innovative apparatus for providing a fast means for changing the RF frequency of signals sent by a base station to RF tags. Optional RF switch **70** is controlled by computer **12** over line **71** to switch either RF generator **50** or optional RF generator **60** to the rest of the base station transmitter **10**.

For a time t p RF generator **50** is connected via lines **81** and **52** through switch **70** to an optional signal splitter **80** which divides the RF signal coming from the switch **70**. A small part of the RF energy from RF generator **50** is tapped off in splitter **80** to be sent to an RF receiver (not shown) via line **82**. (The RF receiver uses the frequency as a comparison to detect the backscattered radiation from the tags.) Most of the RF energy from RF generator **50** is sent to amplifier modulator module **90** via line **91**. Amplifier/Modulator module **90** is controlled via line **93** by computer **12**, and sends amplified and optionally modulated RF energy over line **94** to antenna **14**.

When the base station transmitter **10** is transmitting power to the tag **17**, and shown here for simplicity as not sending a modulated communication signal, the RF power and the RF frequency as a function of time are shown in FIG. **4**a and FIG. **4**b respectively. The RF power is on for a pulse time t_p of 300 to 400 milliseconds, for an RF frequency approximately 2.4 Ghz. Then, the power is reduced to a very small amount, which is preferably zero. During part of the time that the computer **12** instructs the amplifier/modulator **90** to cease amplification, a power that is lower than an FCC power limit P_{FCC}, defined as the maximum power that can be sent out of frequency channel being used, is sent out from antenna **14** during a time t_{FCC}, The computer instructs switch **70** to switch from frequency generator **50** to frequency generator **60** during the time t_{FCC}, Well known RF switches such as switch **70** can easily switch from one source to the other in less than a microsecond. During the time t_p which RF generator **50** has been sending RF power at frequency f, to the amplifier, frequency generator **60** has had ample time to change frequencies to frequency f_2 from its previous frequency.

After the computer commands switch **70** to change the amplifier connection from RF generator **50** to RF generator **60**, a frequency is chosen from a frequency list **13** stored in the computer memory or other memory location to be the next frequency to be transmitted, and instructs RF generator **50** to set itself to the next frequency required after frequency f2 so that the sent out frequency can again be changed during the next power off time. The computer then instructs modulator **90** to amplify once again and send the next pulse of RF power to antenna **14**. After the time t_p, the RF generator **50** has settled to the new frequency and the switch **70** switches back to generator **50** during the time the amplifier **90** is turned off again.

The transmitted RF power and frequency during a changeover are shown in FIG. **5***a* and **5***b*respectively. The rise time t_r and fall time t_f of the power during the switching are very important. When the RF power is switched off and on, side bands of frequencies f_1 and f_2 respectively will be generated and sent to the antenna **14**. The allowed frequency broadening depends on the frequency bands used. If the frequency broadening is too great, the sidebands may cause interference, which is not allowed. The frequency broadening becomes greater as t_1 and t_f are reduced. There is thus a limit below which t_1 and t_f may not be reduced. Thus, the off time t_o during which the RF power sent out is reduced below power P_{min}, where P_{min} is the power which can sustain the energy in the tag energy store **19** above the level needed by the tag electronics **20**, must be greater than t_{FCC} plus the time taken to reduce power from P_{min} to P_{FCC} plus the time taken to raise the power again from P_{FCC} to P_{min}. For example, in the 2.4 Ghz band, the off time t_o must be longer than approximately 700 nanoseconds to allow for both the rise and fall times shown in FIG. **5***a*. More preferably, the off time is longer than 10 microseconds.

This means that the off time t_o must be shorter than a first limit time because the tag will lose memory or other tag function, and longer than a second limit time, so that the frequency sent may change without introducing interfering levels of RF power outside the allowed channels.

The frequency shifts of the transmitter can be random or can be programmed to a particular pattern such as a ramp or stair step pattern which used sufficient frequencies in the bandwidth that the limits on average power in a particular frequency would not exceed regulations. A pseudo random pattern is the most preferred pattern.

A preferred method of the invention is given by the flow chart **600** in FIG. **6**, and comprises the steps of:

610 Determining a first list of a large plurality of allowed frequencies.

620 Optionally arranging the first list of the large plurality of allowed frequencies as a pseudo randomly ordered second list of a large plurality of allowed frequencies f_n.

630 Initializing the process by setting n=1.

640 Transporting RF power for a time t_p from a base station to a radio frequency transponder at a frequency f_n chosen from the random ordered second list of large plurality of allowed frequencies.

650 Ceasing to transmit power for a time t_o.

660 Setting n=n+1 and returning to step **640**.

Given this disclosure, alternative equivalent embodiments would become apparent to one skilled in the arts that are within the contemplation of the inventors. For example, different times t_p for different frequencies, and different off times t_o, as long as the pauses in the power transmission are less than that time which would affect critical electronic components of the tag, are foreseen.

We claim:

1. A method of transporting Radio Frequency (RF) energy to an RF transponder (RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising the steps of:

(a) transporting for a first time RF electromagnetic wave energy from a base station having a base station antenna to the RF tag, the RF energy having a first frequency f_1;then

(b) ceasing to transport RF energy during an off time t_o, where the off time t_o is less than a time where the RF tag loses one or more functions; and then

(c) transporting for a second time RF electromagnetic wave energy from the base station to the RF tag, the RF energy having a second frequency f_2 different from the first frequency f_1, the tag antenna and the rectifying circuit of the RF tag being adapted for receiving power at frequencies f_1 and f_2.

2. The method of claim **1**, wherein the off time t_o is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

3. The method of claim **1**, wherein steps a to c are repeated with different frequencies f_1 and f_2.

4. The method of claim **3**, wherein steps a to c are repeated a large number of times with a large plurality of different frequencies chosen in order from a randomly ordered list of different frequencies.

5. The method of claim **4**, where the off time t_o is less than 400 milliseconds.

6. The method of claim **5**, where the off time t_o is less than 400 microseconds.

7. The method of claim **6**, where the off time t_o is less than 50 microseconds.

8. The method of claim **1**, wherein the RF tag further comprises:

and independent source of energy; and

a switching means responsive to the RF energy transported to the tag adapted to connect the independent source of energy to the tag electronics when RF energy is transported to the tag.

9. The method of claim **8**, wherein the switching means is controlled by a tag decision means responsive to the RF energy transported to the tag.

10. A method of transporting Radio Frequency (RF) energy to an RF transponder (RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising the steps of:

a) determining a list of a large plurality of different frequencies;

b) transporting RF electromagnetic wave energy for a first time from a base station to the remote RF tag at a first frequency chosen from the list of large plurality of different frequencies;

c) ceasing to transport RF energy during an off time t_o, where the off time is less than a time where the tag loses one or more functions;

d) repeating steps b) and c) using frequencies chosen in order from the list.

11. The method of claim **10**, wherein the list is a list of frequencies in pseudo random order.

12. The method of claim **11**, wherein the tag antenna and the rectifying circuit of the remote RF tag are adapted to receive energy transmitted at each frequency of the list of frequencies in pseudo random order.

13. A base station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending RF signal;

an RF amplifier/modulator for receiving the RF signal and for sending RF power to antenna; and

a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where the RF tag energy store is depleted so that the tag electronics do not function.

14. The base station of claim **13**, wherein the RF generator comprises:

a first RF generator for generating the frequency f_1;

a second RF generator for generating the frequency f_2; and

and RF switch, wherein the computer controls the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator.

15. The bases station of claim **13**, where the time during which the power is reduced is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

16. The base station of claim **13**, where the time during which the power is reduced is less than 400 milliseconds.

17. The base station of claim **16**, where the time during which the power is reduced is less than 400 microseconds.

18. The base station of claim **17**, where the time during which the power is reduced is less than 50 microseconds.

19. A system for transporting RF energy from a base station to one or more remote RF tags, comprising:

an RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving

energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics; and

a base station comprising an RF generator, and RF amplifier/modulator for sending RF power to an antenna; and a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier /modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where the RF tag loses one or more functions.

20. The system of claim **19**, where the RF generator comprises:

a first RF generator for generating the frequency f_1;

a second RF generator for generating the frequency f_2;

an RF switch, wherein the computer controls the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator.

21. The system of claim **19**, where the time during which the power is reduced is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

22. The system of claim **19**, where the time during which the power is reduced is less than 400 milliseconds.

23. The system of claim **22**, where the time during which the power is reduced is less than 400 microseconds.

24. The system of claim **23**, where the time during which the power is reduced is less than 50 microseconds.

25. The system of claim **19**, where the RF generator comprises:

a first RF generator for generating the frequency f_1;

a second RF generator for generating the frequency f_2; and

an RF switch, wherein the computer controls the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator.

26. A base station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending an RF signal, where the RF generator comprises a first RF generator for generating a frequency f_1, a second RF generator for generating a frequency f_2, and an RF switch;

an RF amplifier/modulator for receiving the RF signal and for sending RF power to an antenna;

and

a computer, the computer controlling the RF generator to change from the first frequency f_1 to the second frequency f_2 controlling the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced less than the time where the RF tag loses one or more functions.

27. A bases station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending RF signal;

an RF amplifier/modulator for receiving the RF signal and for sending RF power to an antenna;

and

a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where RF tag loses one or more functions and the time during which the power is reduced is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

28. A base station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending an RF signal;

an RF amplifier/modulator for receiving the RF signal for sending RF power to an antenna;

and

a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where the RF tag loses one or more functions and the time during which the power is reduced is less than 400 milliseconds.

29. The base station of claim **28**, where the time during which the power is reduced is less than 400 microseconds.

30. The base station of claim **29**, where the time during which the power is reduced is less than 50 microseconds.

* * * * *

EXHIBIT E

US005912632A

United States Patent [19]

Dieska et al.

[11] **Patent Number: 5,912,632**

[45] **Date of Patent: Jun. 15, 1999**

[54] **SINGLE CHIP RF TAG OSCILLATOR CIRCUIT SYNCHRONIZED BY BASE STATION MODULATION FREQUENCY**

[75] Inventors: **David E. Dieska**, Longwood, Fla.; **Daniel Joseph Friedman**, Tarrytown, N.Y.; **Kenneth Alan Goldman**, Norwalk, Conn.; **Harley Kent Heinrich**, Brewster, N.Y.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **08/780,765**

[22] Filed: **Jan. 8, 1997**

[51] **Int. Cl.**[6] **H04Q 5/22**; H04Q 7/00; H03L 7/00

[52] **U.S. Cl.** **340/825.54**; 455/31.1; 455/37.1; 331/23; 331/10

[58] **Field of Search** 340/825.5, 825.54, 340/825.36, 825.69, 825.72; 342/51; 455/31.1, 37.1, 34.3, 38.3; 331/23

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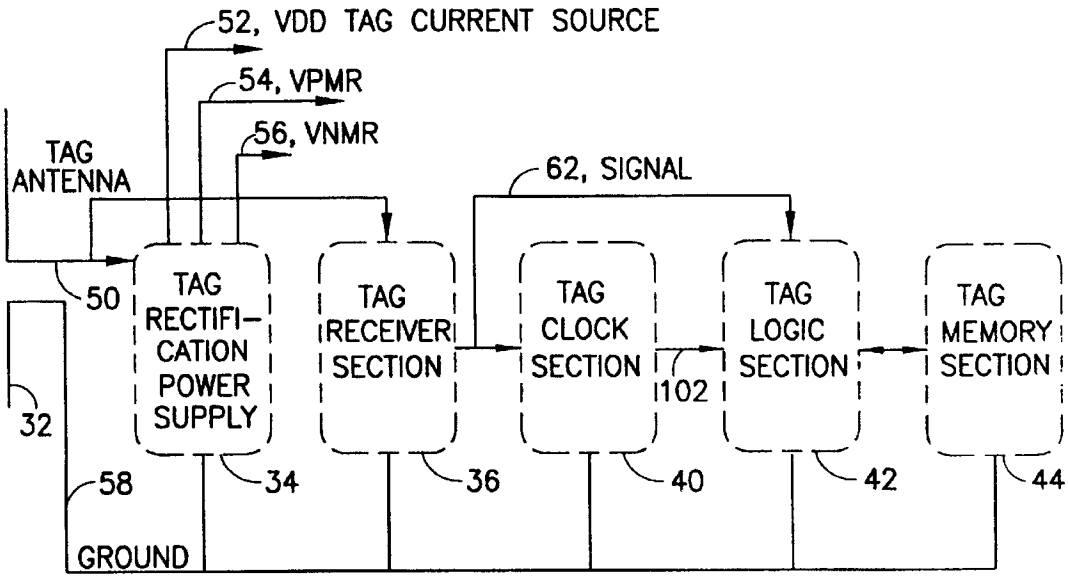
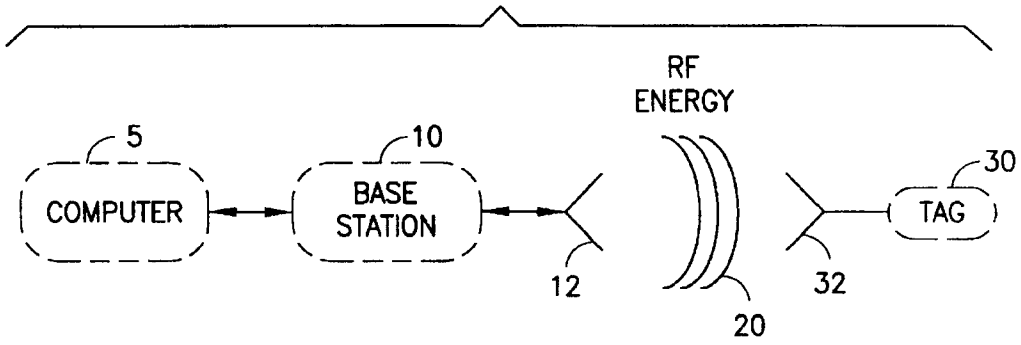
Primary Examiner—Michael Horabik
Assistant Examiner—Anthony A. Asongwed
Attorney, Agent, or Firm—Rodney T. Hodgson

[57] **ABSTRACT**

A Radio Frequency (RF) transponder (tag), method, and system, whereby the tag has a low current tag oscillator, the oscillation frequency of the tag oscillator set by RF signal from a base station.

28 Claims, 9 Drawing Sheets

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COMPUTER
BASE
STATION
TAG
12
32
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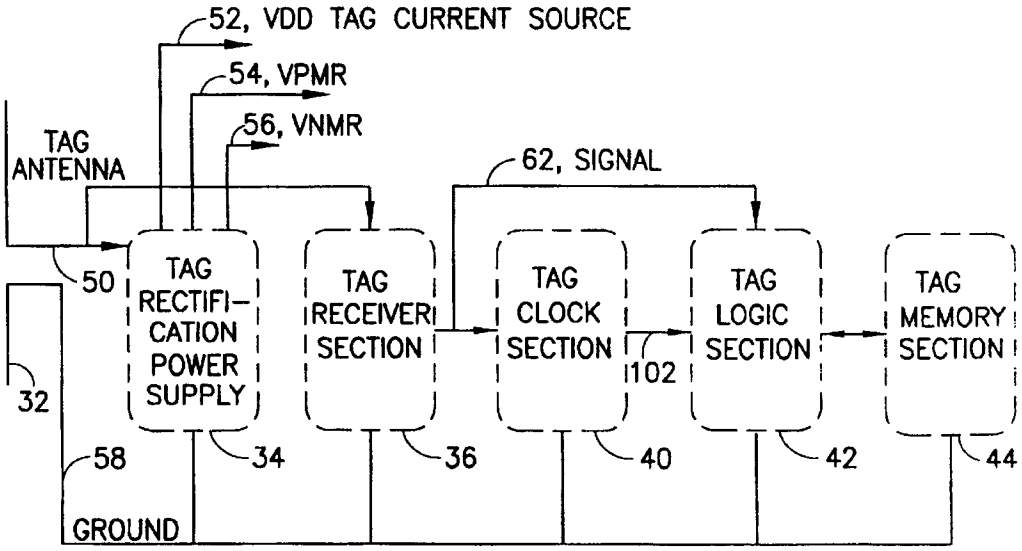
FIG.1


52, VDD TAG CURRENT SOURCE
54, VPMR
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TAG
RECEIVER
SECTION
TAG
CLOCK
SECTION
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MEMORY
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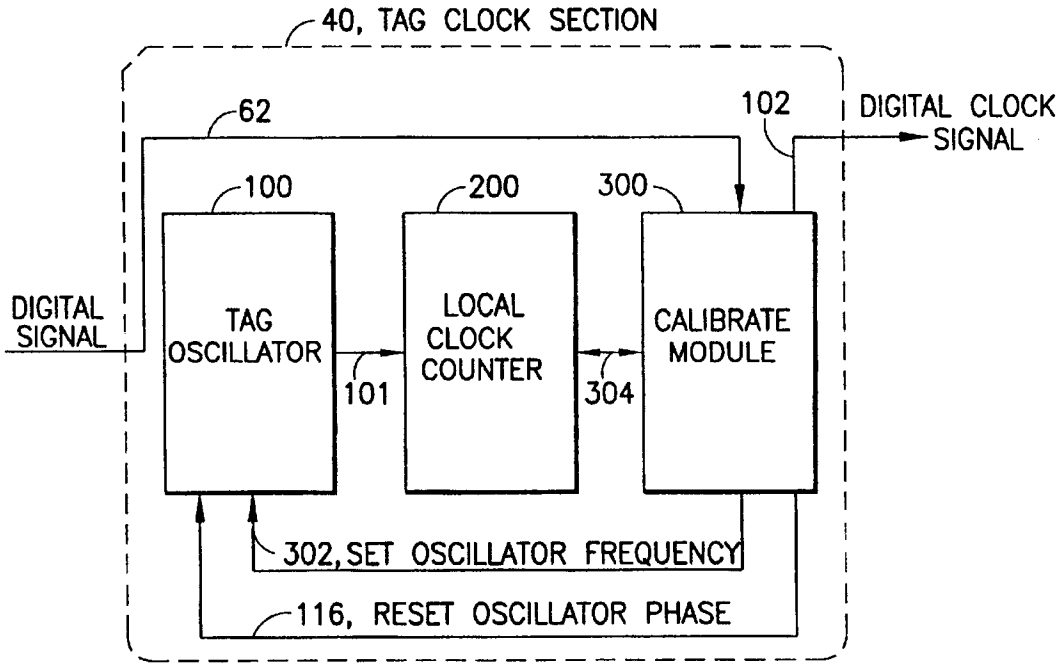
GROUND

FIG.2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102
DIGITAL CLOCK SIGNAL
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200
300
DIGITAL SIGNAL
TAG OSCILLATOR
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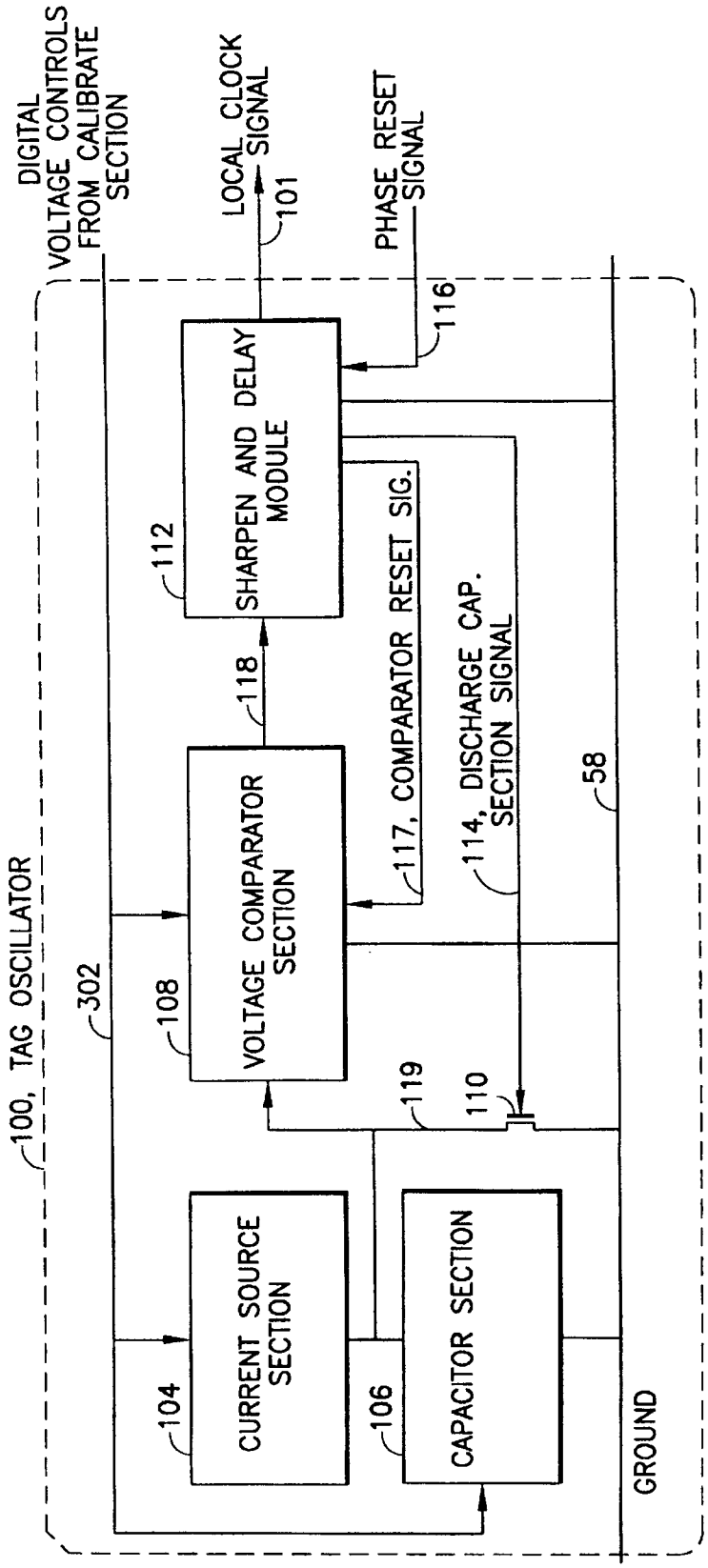
CALIBRATE MODULE
101
304
302, SET OSCILLATOR FREQUENCY
116, RESET OSCILLATOR PHASE

FIG.3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PHASE RESET SIGNAL
116
SHARPEN AND DELAY MODULE
112
118
VOLTAGE COMPARATOR SECTION
108
117, COMPARATOR RESET SIG.
114, DISCHARGE CAP. SECTION SIGNAL
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302
100, TAG OSCILLATOR
119
110
CURRENT SOURCE SECTION
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CAPACITOR SECTION
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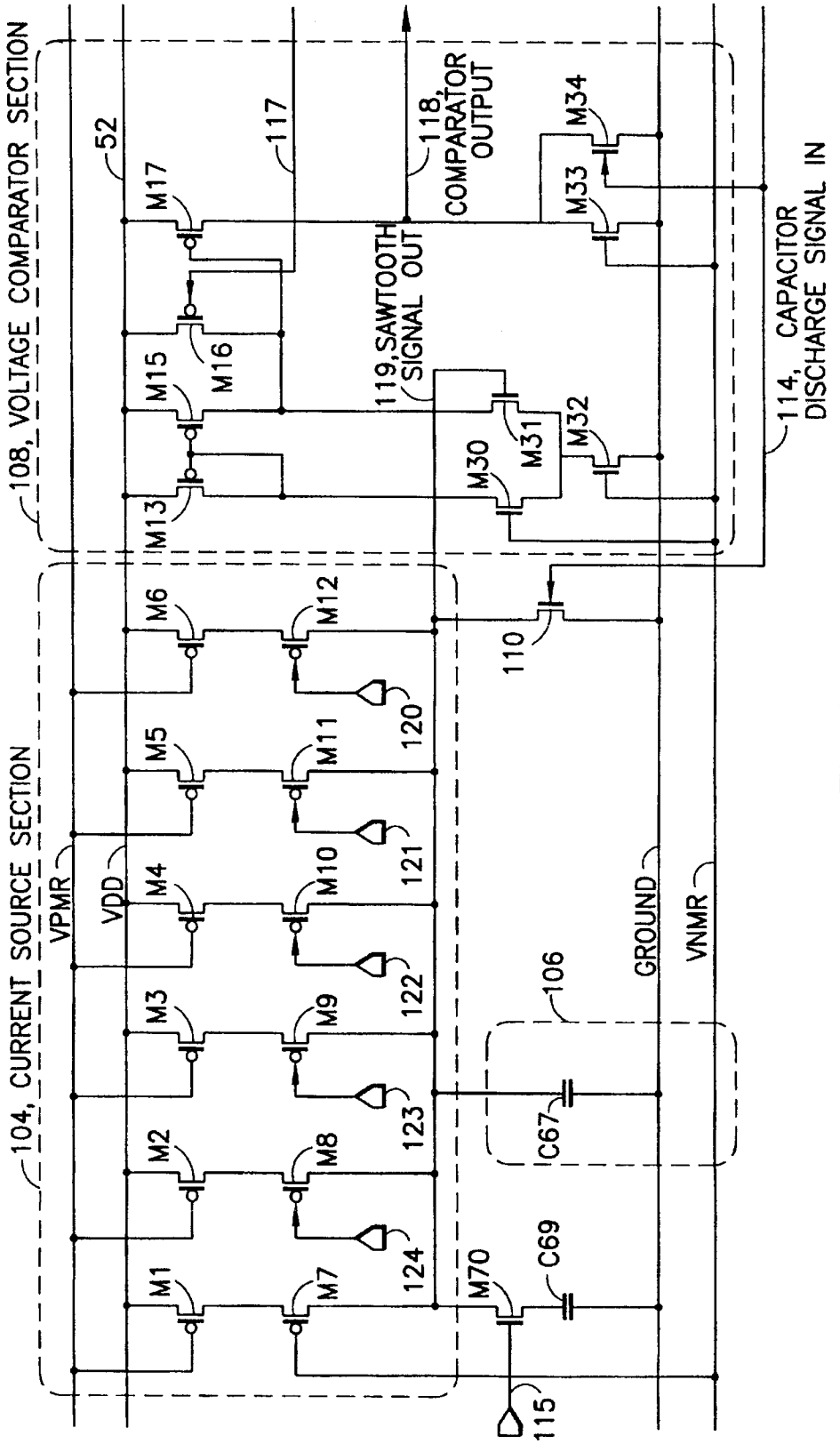
GROUND

FIG.4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117
118, COMPARATOR OUTPUT
119, SAWTOOTH SIGNAL OUT
114, CAPACITOR DISCHARGE SIGNAL IN
M17
M16
M15
M13
M34
M33
M32
M31
M30
M6
M5
M4
M3
M2
M1
M12
M11
M10
M9
M8
M7
M70
110
120
121
122
123
124
VPMR
VDD
GROUND
VNMR
106
C67
C69
115

FIG.5a

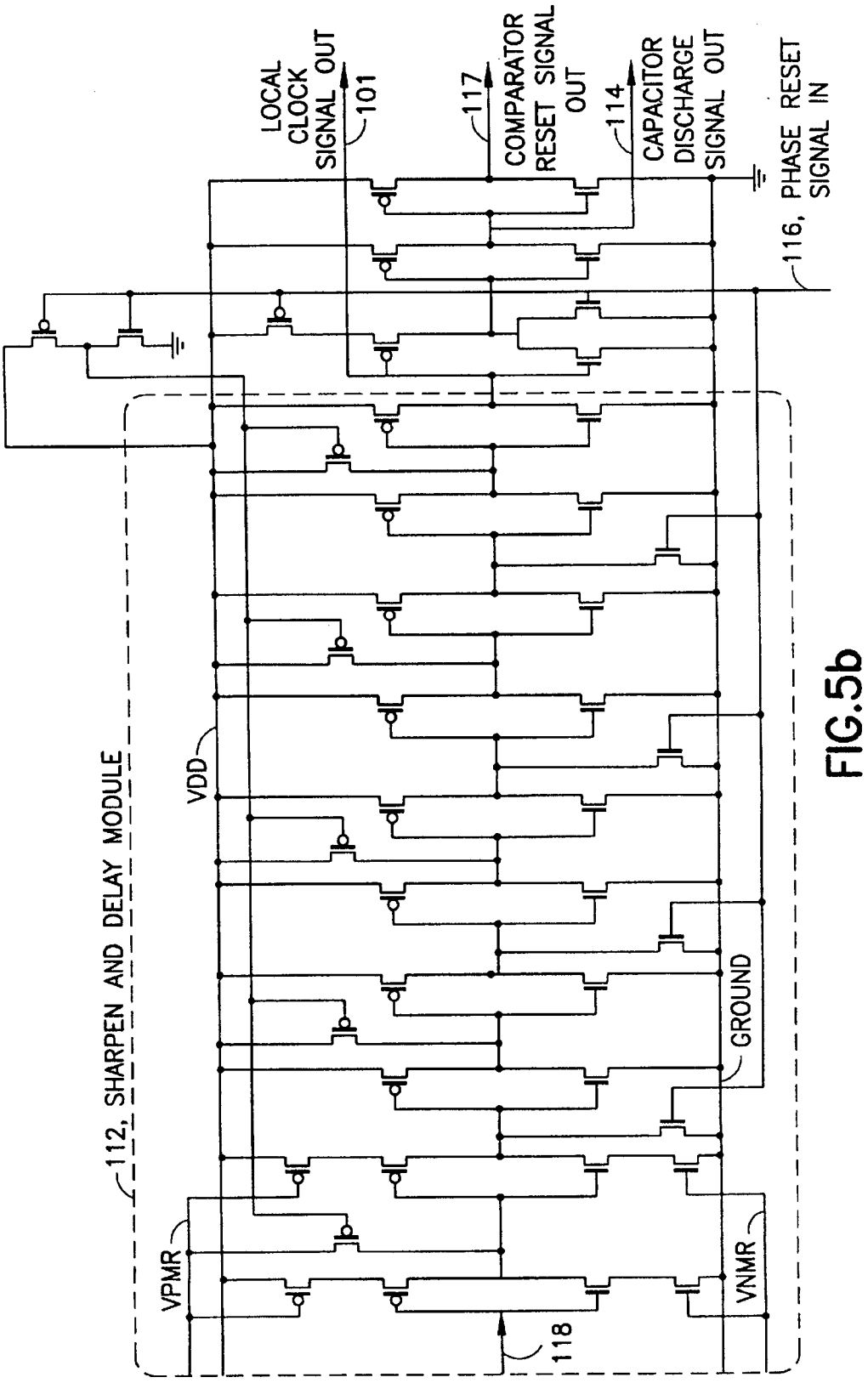
LOCAL CLOCK SIGNAL OUT
101
117
COMPARATOR RESET SIGNAL OUT
114
CAPACITOR DISCHARGE SIGNAL OUT
116, PHASE RESET SIGNAL IN
112, SHARPEN AND DELAY MODULE
VDD
GROUND
VPMR
VNMR
118

FIG.5b

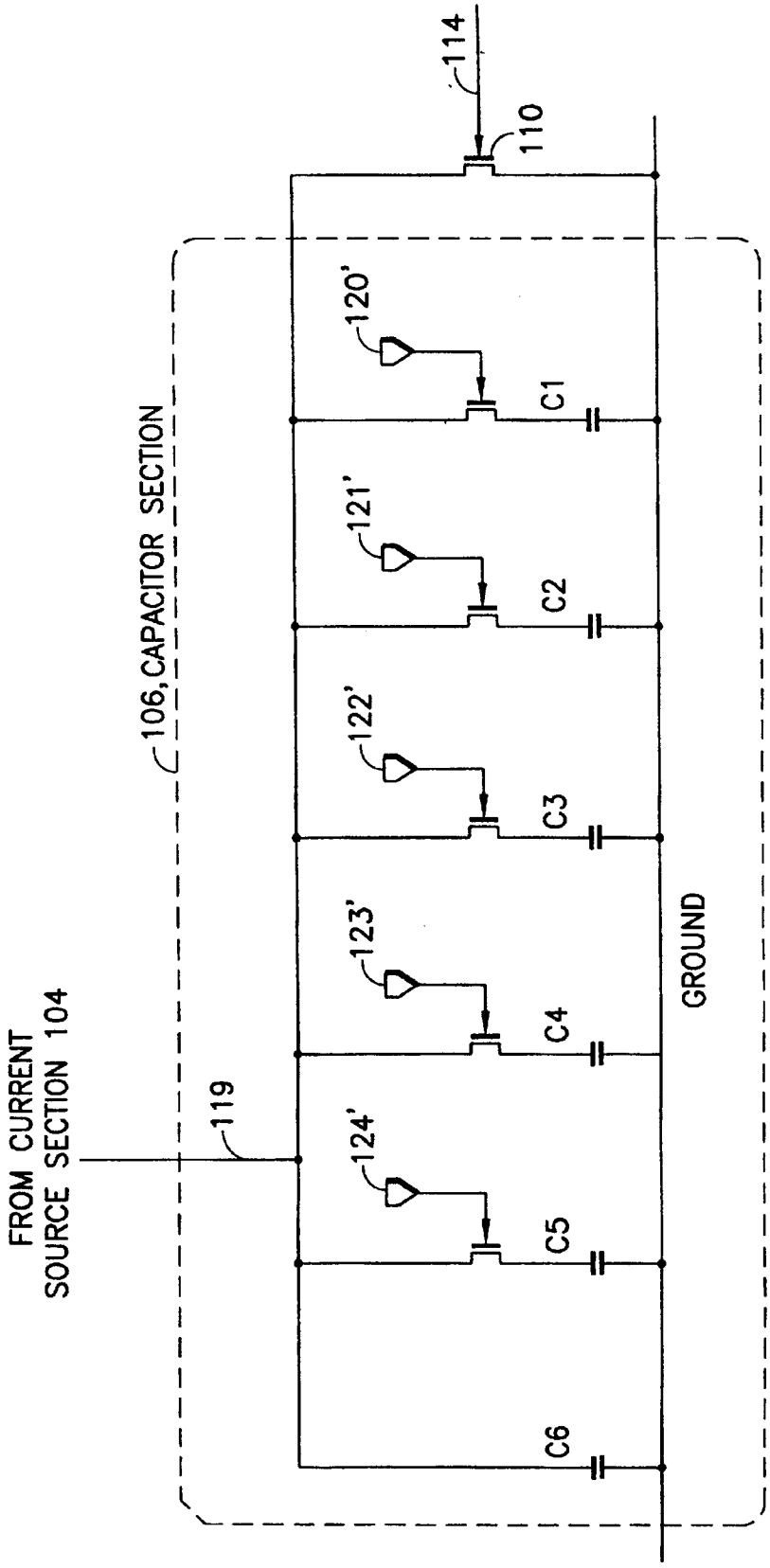
114
110
120'
C1
121'
C2
122'
C3
123'
C4
124'
C5
C6
106, CAPACITOR SECTION
GROUND
119
FROM CURRENT SOURCE SECTION 104

FIG.6

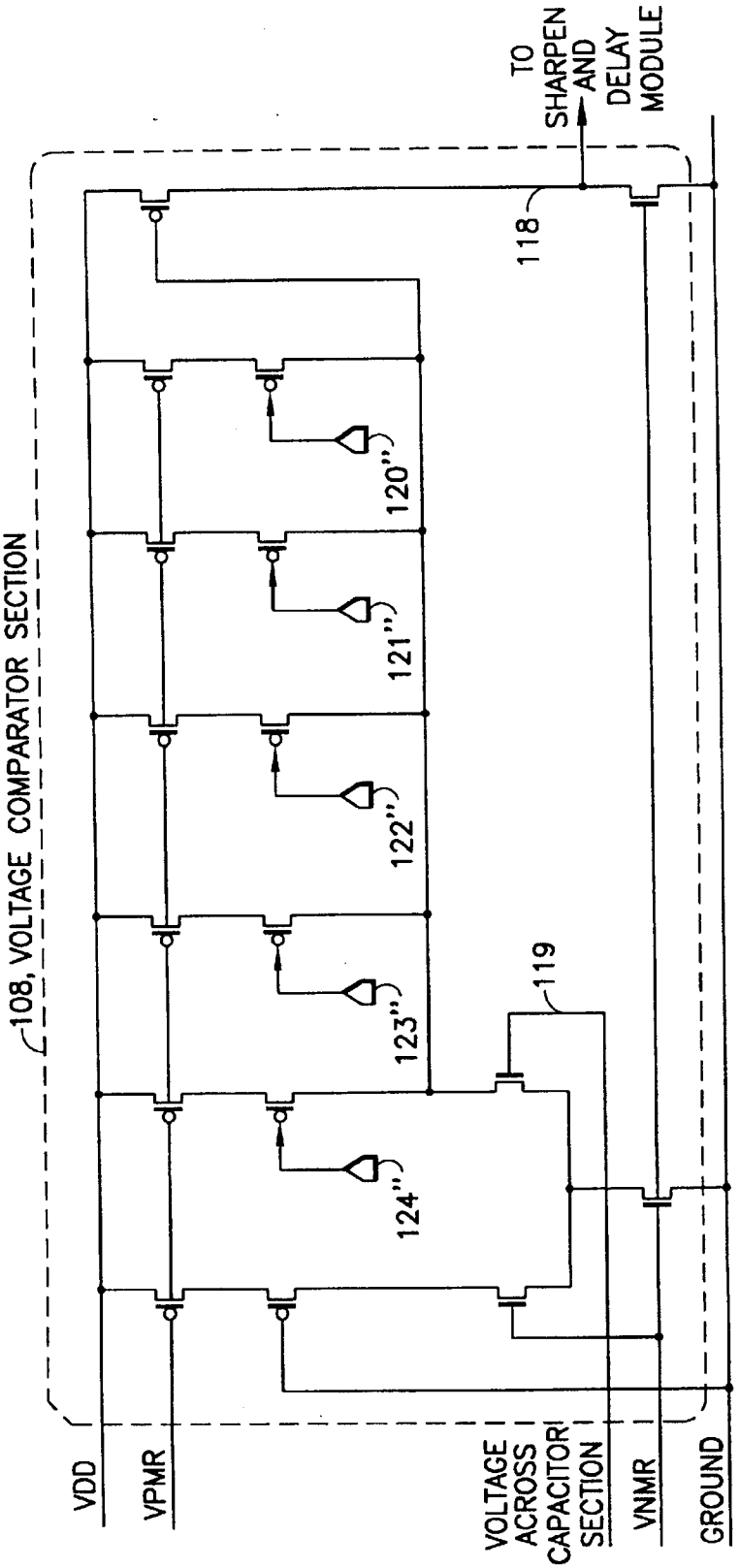
TO SHARPEN AND DELAY MODULE
118
120''
121''
122''
123''
124''
119
108, VOLTAGE COMPARATOR SECTION
VDD
VPMR
VOLTAGE ACROSS CAPACITOR SECTION
VNMR
GROUND

FIG.7

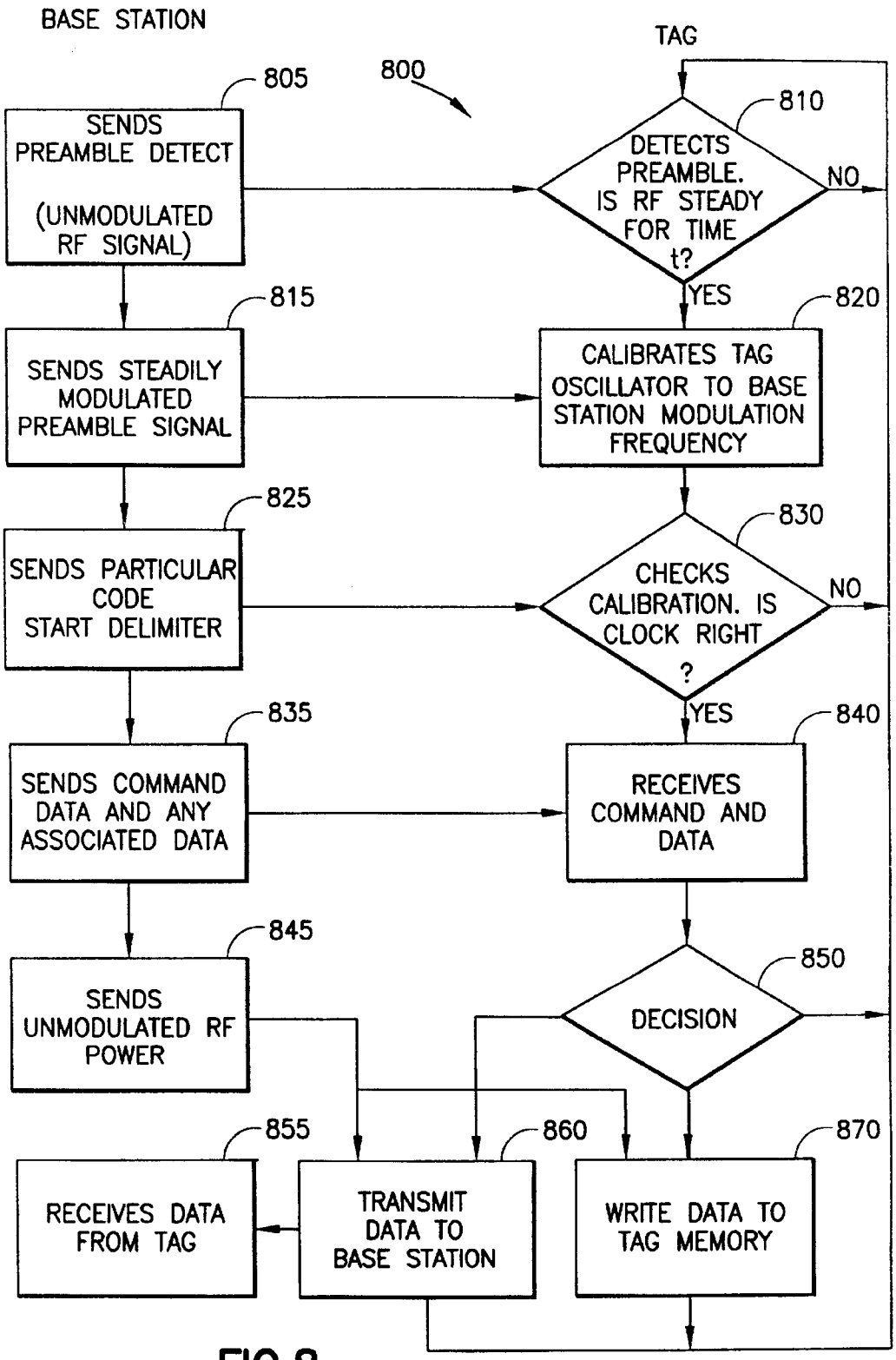
BASE STATION
TAG
800
805
SENDS PREAMBLE DETECT (UNMODULATED RF SIGNAL)
810
DETECTS PREAMBLE. IS RF STEADY FOR TIME t?
NO
YES
815
SENDS STEADILY MODULATED PREAMBLE SIGNAL
820
CALIBRATES TAG OSCILLATOR TO BASE STATION MODULATION FREQUENCY
825
SENDS PARTICULAR CODE START DELIMITER
830
CHECKS CALIBRATION. IS CLOCK RIGHT ?
NO
YES
835
SENDS COMMAND DATA AND ANY ASSOCIATED DATA
840
RECEIVES COMMAND AND DATA
845
SENDS UNMODULATED RF POWER
850
DECISION
855
RECEIVES DATA FROM TAG
860
TRANSMIT DATA TO BASE STATION
870
WRITE DATA TO TAG MEMORY

FIG.8

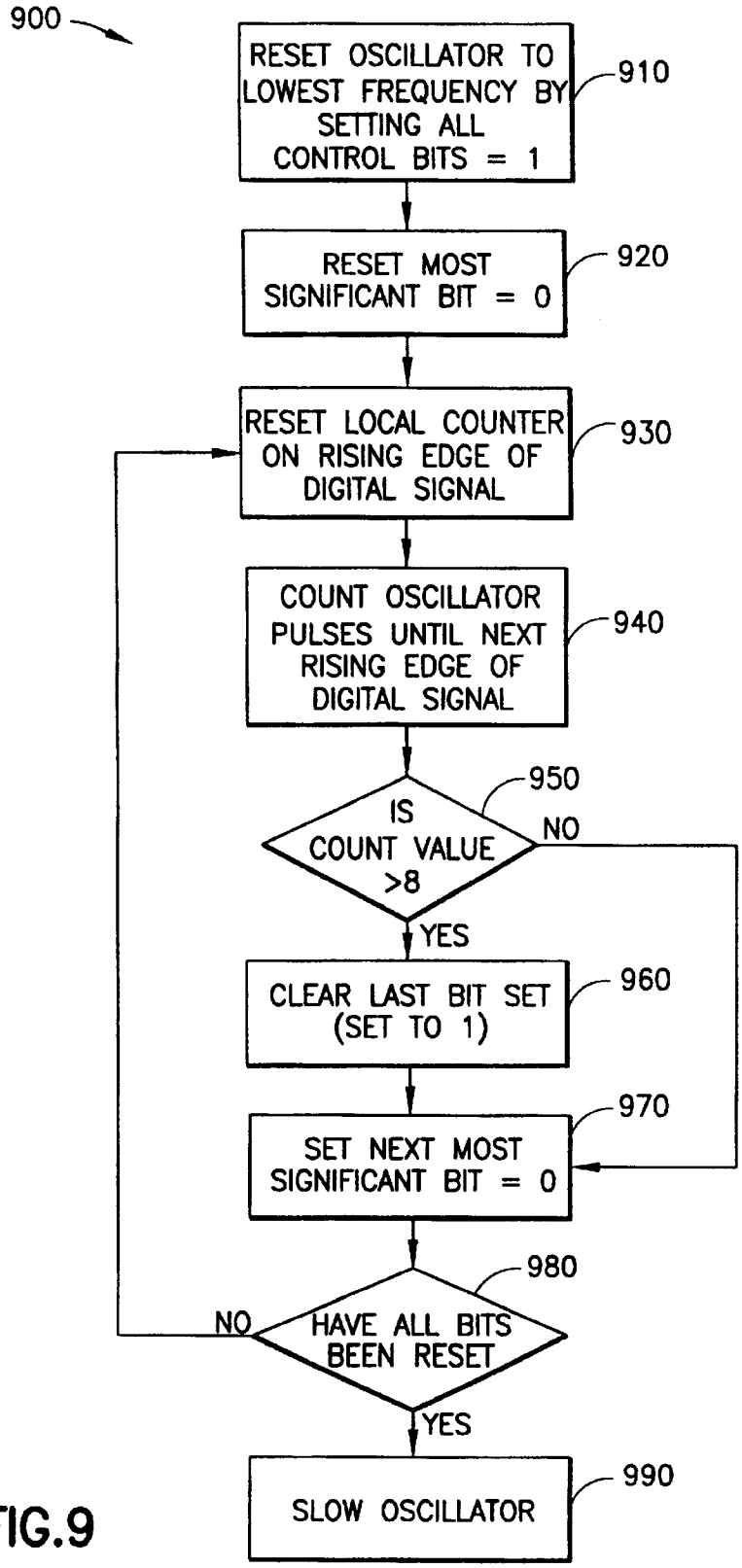
900
RESET OSCILLATOR TO LOWEST FREQUENCY BY SETTING ALL CONTROL BITS = 1
910
RESET MOST SIGNIFICANT BIT = 0
920
RESET LOCAL COUNTER ON RISING EDGE OF DIGITAL SIGNAL
930
COUNT OSCILLATOR PULSES UNTIL NEXT RISING EDGE OF DIGITAL SIGNAL
940
IS COUNT VALUE >8
950
NO
YES
CLEAR LAST BIT SET (SET TO 1)
960
SET NEXT MOST SIGNIFICANT BIT = 0
970
HAVE ALL BITS BEEN RESET
980
NO
YES
SLOW OSCILLATOR
990

FIG.9

SINGLE CHIP RF TAG OSCILLATOR CIRCUIT SYNCHRONIZED BY BASE STATION MODULATION FREQUENCY

FIELD OF THE INVENTION

The field of the invention is the field of Radio Frequency (RF) transponders (RF Tags) which receive RF electromagnetic radiation from a base station and send information to the base station by modulating the load of an RF antenna.

BACKGROUND OF THE INVENTION

RF Tags can be used in a multiplicity of ways for locating and identifying accompanying objects, items, animals, and people, whether these objects, items, animals, and people are stationary or mobile, and transmitting information about the state of the of the objects, items, animals, and people. It has been known since the early 60's in U.S. Pat. No. 3,098,971 by R. M. Richardson, that electronic components on a transponder could be powered by radio frequency (RF) power sent by a "base station" at a carrier frequency and received by an antenna on the tag. The signal picked up by the tag antenna induces an alternating current in the antenna which can be rectified by an RF diode and the rectified current can be used for a power supply for the electronic components. The tag antenna loading is changed by something that was to be measured, for example a microphone resistance in the cited patent. The oscillating current induced in the tag antenna from the incoming RF energy would thus be changed, and the change in the oscillating current led to a change in the RF power radiated from the tag antenna. This change in the radiated power from the tag antenna could be picked up by the base station antenna and thus the microphone would in effect broadcast power without itself having a self contained power supply. In the cited patent, the antenna current also oscillates at a harmonic of the carrier frequency because the diode current contains a doubled frequency component, and this frequency can be picked up and sorted out from the carrier frequency much more easily than if it were merely reflected. Since this type of tag carries no power supply of its own, it is called a "passive" tag to distinguish it from an active tag containing a battery. The battery supplies energy to run the active tag electronics, but not to broadcast the information from the tag antenna. An active tag also changes the loading on the tag antenna for the purpose of transmitting information to the base station.

The "rebroadcast" or "reflection" of the incoming RF energy at the carrier frequency is conventionally called "back scattering", even though the tag broadcasts the energy in a pattern determined solely by the tag antenna and most of the energy may not be directed "back" to the transmitting antenna.

In the 70's, suggestions to use tags with logic and read/write memories were made. In this way, the tag could not only be used to measure some characteristic, for example the temperature of an animal in U.S. Pat. No. 4,075,632 to Baldwin et. al., but could also identify the animal. The antenna load was changed by use of a transistor. A transistor switch also changed the loading of the transponder in U.S. Pat. No. 4,786,907 by A. Koelle.

Prior art tags have used electronic logic and memory circuits and receiver circuits and modulator circuits for receiving information from the base station and for sending information from the tag to the base station.

The continuing march of semiconductor technology to smaller, faster, and less power hungry has allowed enormous increases of function and enormous drop of cost of such

tags. Presently available research and development technology will also allow new function and different products in communications technology.

Prior art tags which use a different frequency than that of the base station carrier frequency are disadvantageous in that the tag and base station antennas usually have maximum efficiency if it they are designed for a single frequency.

Prior art battery tags which use the same frequency as that of the base station must modulate the antenna reflectance with a well defined modulation frequency so that the base station can distinguish the modulated reflected signal from the various sources of noise. Prior art battery tags carry an oscillator as part of the circuitry needed to receive and send data between the tag and the base station. This oscillator needs a local frequency standard to fix the tag modulation frequency so that the base station can easily and cheaply receive and demodulate the modulated signal sent by the tag. Such local frequency standards are very expensive and hard to integrate on a monolithic semiconductor chip. The tags require an oscillator which draws a lot of current from the tag power supply, either from a battery tag or a passive tag, which lowers either the life of the battery or the range of the tag, respectively. In addition, the base station may have to adjust to the modulation frequency sent out by the tag, which requires that the base station listens to the tag in the first step of the communication procedure, instead of talking to the tag first. This complicates communication procedures when there are multiple tags in the field. Each tag may be sending signals to the base station with a different modulation frequency, and the signals will interfere.

RELATED APPLICATIONS

Copending patent applications assigned to the assignee of the present invention and hereby incorporated by reference, are:

- Ser. No. 08/303,965 filed Sep. 9, 1994 entitled RF Group Select Protocol, by Cesar et. al now U.S. Pat. No. 5,673,037;
- Ser. No. 08/304,340 filed Sep. 9, 1994 entitled Multiple Item RF ID protocol, by Chan et. al. now U.S. Pat. No. 5,550,547;
- Ser. No. 08/521,898 filed Aug. 31, 1995 entitled Diode Modulator for RF Transponder by Friedman et al. now U.S. Pat. No. 5,606,325;
- application submitted Aug. 9, 1996 entitled RFID System with Broadcast Capability by Cesar et al.; and
- application submitted Jul. 29, 1996 entitled RFID transponder with Electronic Circuitry Enabling and Disabling Capability, by Heinrich et al.

OBJECTS OF THE INVENTION

It is an object of the invention to produce an RF transponder comprising circuits which can be made at low cost. It is a further object of the invention to produce an RF transponder which can be used at high frequencies. It is a further object of the invention to produce an RF transponder with maximum range. It is a further object of the invention to produce an RF transponder with circuits which require very little current. It is a further object of the invention to produce an electronic chip for an RF transponder which can be produced simply with standard semiconductor manufacturing techniques. It is a further object of the invention to produce a communication system for communicating with the RF transponder of the present invention. It is a further object of the invention to produce a system for controlling

the communication system using the present invention. It is a further object of the invention to produce a system for using and changing information received from the transponder of the present invention.

SUMMARY OF THE INVENTION

The present invention is to have a passive RF tag with a tag oscillator with an oscillation frequency which the tag can lock to a signal sent from the base station to the tag. An innovative low current oscillator design accomplishes this invention. Innovative low current ancillary circuits are also provided. The preferred signal is the modulation frequency of the modulated RF signal that the base station sends to the tag. In this way, an expensive local frequency standard on the tag is not needed, and an inexpensive oscillator can be constructed solely from the transistors and capacitors which are easily and cheaply made on a single chip RF tag. The base station is also cheaper, since the tag sends information modulated at a frequency related to the modulation frequency of the base station, and the base station does not have to have an expensive oscillator circuit which tracks wide excursions of the tag modulation frequency. The result is better noise performance since the base station looks in a much narrower frequency band for the tag signal than would otherwise be the case with inexpensive oscillator circuits on the tag.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**. A system of a base station and an RF tag.

FIG. **2**. A block diagram of part of the RF tag.

FIG. **3**. A block diagram of the tag clock section.

FIG. **4**. A block diagram of a preferred tag oscillator.

FIG. **5***a*. and **5***b*. A circuit diagram for a preferred embodiment of a tag oscillator.

FIG. **6**. A circuit diagram for an alternative preferred embodiment of a capacitor section for a tag oscillator.

FIG. **7**. A circuit diagram for an alternative preferred embodiment of a voltage comparator section for a tag oscillator.

FIG. **8**. A flow chart of a preferred method of implementing and using the apparatus of the invention.

FIG. **9**. A flow chart of a preferred method of calibrating the tag oscillator.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** shows a system of a base station **10** having an associated computer **5** sending RF energy **20** from base station antenna **12** to a tag antenna **32** associated with an RF tag **30**. The RF frequency f_0 is preferably above 100 MHZ, more preferably above 900 MHZ, and most preferably above 2,300 MHZ. The RF signal is preferably amplitude modulated at a frequency f_1 greater than 1 Khz, more preferably between 5 and 150 kHz, and most preferably between 20 and 60 kHz. However, the RF signal may also be modulated by frequency modulation or by phase modulation methods, as is well known in the art of RF signal propagation. The RF tag **30** may be a passive tag which receives all the energy needed to carry out the tag functions from the RF field broadcast by the base station, or it may be an active tag which carries a battery to store the required energy. An active tag may, and a passive tag will, change the loading on the tag antenna **32** to change the antenna reflectivity and thus communicate with the base station **10**.

FIG. **2** shows a block diagram of the tag antenna **32** and part of the RF tag **30**. (Neither a possible RF tag transmitter section nor other sections such as measurement sections nor alarm section nor enable/disable sections are shown.) The RF antenna **32** feeds RF power to the tag rectification power supply **34**. A battery tag would replace block **34** with a battery (not shown). In the preferred embodiment shown in FIG. **2**, a tag rectification signal receiving section **36** comprising an RF diode, a signal capacitor, and a signal capacitor current drain is separate from the tag rectification power supply, but the oscillator section of the invention is also contemplated in the case that section **36** is part of the tag rectification power supply **34**. The tag power supply **34** supplies current at voltage VDD on line **52**, and optionally supplies voltages VPMR, and VNMR on lines **54** and **56** respectively. These lines are used to power and control the various devices on the tag. The RF antenna **32** has two connections to the tag **30**, denoted here by lines **50** and **58**. Line **58** is the conventional ground.

The tag rectification signal receiving section **36** receives an RF signal which is preferably amplitude modulated at a frequency f_1 from the antenna **32** over line **50**, and rectifies and demodulates the RF signal and delivers a digital signal to the rest of the tag electronics over line **62**. If the RF is modulated with a steady modulation frequency f_1, the output of the signal receiving section **36** is preferably a series of square pulses of unit voltage at a frequency f_1. However, any pattern or subpattern in the signal sent out from the base station could be used to generate an output of the signal receiving section **36** in order to adjust the frequency and optionally the phase of the tag oscillator.

The tag clock section **40** receives the digital demodulated digital signal from line **62** and sets the tag oscillator frequency using the modulation frequency f_1 of the modulated RF signal as will be explained later.

The tag clock section **40** delivers a digital clock signal on line **102** to the tag logic section **42**, to the tag memory section **44**, and to other tag electronic sections as needed.

FIG. **3** is a block diagram of the tag clock section **40**. The tag oscillator **100** must use less than 500 microamperes of current from the tag power supply **34** in order to avoid drawing down the tag voltage VDD and lowering the range of the tag. It is more preferred that the tag oscillator uses less than 50 microamperes of current. It is even more preferred to have the tag oscillator draw less than 5 microamperes of current when the tag oscillator is oscillating with maximum oscillation frequency, and less than 150 nanoamperes of current when the tag oscillator is oscillating with minimum frequency. In a preferred embodiment, the tag oscillator **100** comprises an oscillator with a block diagram given later in FIG. **4**.

The tag oscillator frequency is set by the voltages supplied by a connection denoted **302** from a calibrate module **300**. The tag oscillator **100** supplies a local clock signal to the local clock counter **200** over line **101**. The local clock counter **200** counts the clock ticks of the local clock signal since the local clock counter **200** has been reset and passes the count to the calibrate module **300** via a connection **304**. The calibrate module **300** resets the local clock counter **200** via the connection **304** (and optionally resets the phase of the oscillator **100** over connection **116**) on a rising edge of the digital input signal on line **62**, and sets the voltages controlling the frequency of oscillator **100** to give a set number of counts between two rising edges of the digital input signal **62** when the base station **10** is sending a steadily modulated RF signal. The calibrate module **300** sends the voltages

controlling the frequency of the oscillator **100** over line **302**. The oscillator **100** frequency is thus determined by the modulation frequency of the RF energy **20** transmitted by the base station **10**. While the calibrate module may carry out its functions using a rising edge of the digital input signal, it is clear to one skilled in the art that the falling edge of the digital signal, or indeed any characteristic of the signal on line **62**, may serve as well. The calibrate module sends the digital clock signal to the rest of the tag electronics over line **102**.

FIG. **4** is a block diagram for an oscillator section **100**. A current source section **104** charges a capacitor section **106**. The voltage across capacitor section **106** on line **119** is compared with a reference voltage generated on the chip. The comparison is done in comparator section **108**, and when the voltage reaches a preset comparison voltage, the comparator section **108** sends a signal on line **118** down an optional pulse sharpening and delay section **112**. When the pulse reaches the end of the pulse sharpening and delay section **112**, a local clock signal is sent out on line **101**, and a pulse is sent back on line **114** to transistor **110** which discharges capacitor section **106** so that the voltage across capacitor section **106** falls to a low value. Then the voltage starts to build up until it again reaches the preset comparison voltage. The time between two discharges of the capacitor section **106** is the time between two ticks of the local clock. A series of narrow spikes is sent out from the oscillator section on line **101** representing ticks of the local clock.

A phase reset signal is brought in to the sharpen and delay module on line **116** when, for example, the tag detects a rising or falling edge of the digital signal on line **62**. The sharpen and delay module **112** then sends a pulse on line **114** to the transistor **110** to both discharge the capacitor section **106** and reset the phase of the local clock signal on line **101**. The phase reset signal also serves to clear the sharpen and delay line in the sharpen and delay module **112**. A signal is also sent on line **117** to clear the voltage comparator section **108** when the phase reset signal passes through the sharpen and delay line.

One or more of the sections **104**, **106**, and **108** are digitally controlled by signals from the calibrate module **300** sent out on line **302**. These calibrate module outputs are set using base station output modulation patterns. Thus, the tag oscillator frequency is controlled by the signals from the base station to be one of a plurality of possible discrete frequencies. Circuits for analog control of the tag oscillator are anticipated by the inventors, but the digital control is preferred since the circuits required are more stable and require less current.

The most preferred embodiment of the oscillator section **100** uses an innovative, very low current source section **104** with the value of the current set by the calibrate module using voltages brought to the current source section **104** on connection **302**. FIG. **5***a* shows a circuit diagram of the most preferred circuit of blocks **104**, **106**, and **108** which may produce a clock signal running at approximately 8 times the RF modulation frequency f_1.

Transistors M2–M6 are each capable of sourcing a defined current on to capacitor C67, depending on whether control transistor switches M8–M12 are on or off. Voltages at nodes **120**, **121**, **122**, **123**, and **124** which are set by voltages carried over connection **302**, control transistors M8–M12.

Transistor Ml supplies capacitor C67 with a small current from the tag power supply at voltage VDD. This small current is independent of the calibrate module control on line **302**. When nodes **120–124** are set high by voltages supplied on connection **302** from the calibrate module **300**, transistors M8–M12 do not conduct current. The tag oscillator runs at a relatively low frequency, (since at low current the capacitor C67 charges slowly to the comparison voltage) and the digital clock signal produced on line **102** is used to check whether an unmodulated RF signal is being sent from the base station for a sufficiently long time in the first step of the method of the invention called the preamble detect step. As will be shown later, the system then may calibrate the oscillator by setting voltages on nodes **120–124**. When the tag oscillator is running in the slowest mode, the average current draw is only 100 nA, as the current is drawn through most of the devices shown in FIG. **5***a* and FIG. **5***b* only for a very short time when there is a transition and a clock pulse is produced. As one or more of the control transistors M8–M12 are turned on, the oscillator runs faster, and the feedback from the calibrate module is used to set the nodes **120–124** so that the oscillation frequency is adjusted with respect to the base station RF modulation frequency.

Transistors M1–M6 are p-FETs controlled by the voltage VPMR, and the current through each transistor mirrors the current through a standard p-FET elsewhere on the chip. In the operating regime of the circuit of FIG. **5**, the relative current through each transistor M1–M6 is defined by the geometry of the transistors, as is well known to one skilled in the art of analog integrated circuit design. The currents through transistors M1–M6 are in the ratio 2:1:2:4:8:16 respectively. On the chip, transistors M1–M6 are implemented as multiple devices of the same size. Thus, the transistor with weight **16** is actually **16** identical transistors connected in parallel. (The transistors have dimensions $w=5\mu \times 1=10\mu$ in a preferred implementation.) The current from current source **104** can thus be set at approximately every integral multiple between 2 and 33 of a base current of approximately 35 nA by appropriate adjustment of voltages on nodes **120–124**. There are thus 32 different tag oscillator frequencies that can be generated by the tag oscillator **100**.

It is clear to one of ordinary skill in the art that more or fewer transistors such as M2–M6 could be used to set more or fewer values of the tag oscillator frequency. It is also clear that the settable frequencies are not necessarily equally distributed through the desired frequency region. It is well within the scope of the invention to have non-integral ratios for the currents from transistors M1–M6 to provide finer control near the most desired frequency, and yet allow wider excursions from the mean of the allowed frequencies. It is also well within the scope of the invention to reverse the p and n channel circuits shown in the figures with equivalent n and p channel circuits. The circuit shown is preferable, however, in that the current supplies are somewhat more stable in an environment where VDD may shift and where the ground is more stable.

An alternative preferred embodiment of the oscillator section **100** uses a capacitor section **106** with a value of the capacitance set by the calibrate module using voltages on connection **302**. This embodiment is shown in the circuit diagram of FIG. **6** for the capacitor section **106**. In this case, the current source section **104** would preferably comprise one or two p-fet transistors. The digitally controlled capacitor section **106** shown in FIG. **6** runs at the fastest rate when all capacitors C_1–C_5 are switched off from receiving current from the current source section **104**, and the smallest capacitor C_6 is used. In this case, the variations in manufacture of the limited current supply transistors and the capacitance C_6 would lead to unwanted variations in the maximum tag

oscillation frequency. This disadvantage outweighs the advantage that the oscillator draws approximately the same low constant current at all times (although the current used during the transitions may vary greatly with frequency).

An alternative preferred embodiment of the oscillator section **100** uses a comparison voltage in section **108** with a value of the comparison voltage set by the calibrate module using voltages on connection **302**. This embodiment is shown in the circuit diagram of FIG. **7** for the voltage comparator section **108**. In this case, the current source section **104** would preferably be one or two p-fet transistors, and the capacitance section **106** would be a preferably comprise a single capacitor. This circuit works by providing a controllable way to unbalance the current sources which supply the differential pair in the first stage of the comparator. Unbalancing the current sources serves to move the comparator trip point.

The digitally controlled current source section **104** sketched in the circuit of FIG. **5***a* is preferred over the digitally controlled capacitance section **106** or the digitally controlled voltage comparator section **108** sketched in FIGS. **6** and **7** respectively. The current is extremely low when the oscillator frequency is low, and the stability and predictability of the oscillation frequency is not as important as when the frequency is raised for the purposes of tag conmmunication. At the higher tag oscillator frequencies, the current draw is higher, and as a result the frequency is much more stable and predictable and is less affected by manufacturing and tag environmental variations.

Transistor **M70** and capacitor **C69** are optionally included in the oscillator section to slightly slow the oscillator after the oscillation frequency has been set. Thus, the frequency could be set so that there are approximately 9 counts of the clock in every base station modulation frequency interval. **M70** can then be turned on, which will guarantee that there are less than 9 counts per interval.

A preferred comparator section **108** is also shown in FIG. **5***a*. This voltage comparison circuit is well known to one skilled in the art. For example, see page **333** of Allen and Holberg—CMOS Analog Circuit Design (1987).

The optional sharpen and delay module **112** circuit is shown in FIG. **5***b*. While the signal on line **118** could be used as a clock signal for the tag electronics and could be used to discharge capacitor section **106** through transistor **110** if it were connected to line **114**, the slow rise time of signal on line **118** would waste current in the digital gate using it as input. Furthermore, the oscillator output spike might be too narrow.

The series of resettable inverter circuits in the sharpen and delay module **112** shown in FIG. **5***b* serve to delay and sharpen the final pulse applied to line **102**. The delay allows us to perform computations on both rising and falling edges of the oscillator output with adequate intervening setup and hold time. The sharpen and delay circuit is also more broadly required to ensure a wide enough clock pulse width for use by the digital electronics on the chip. The sharpen and delay circuit is innovative in that it works at low current due to the current limited early gain stages. The circuit is also innovative in that it is resettable, in that the delay line is cleared of data when an oscillator reset is requested. When the circuit without resettability was tried, it was not reliable.

FIG. **8** shows a flow chart **800** of a method of implementing and using the apparatus of the invention. In step **805**, the base station sends out a steady, unmodulated "Preamble Detect" signal. In step **810** the base station oscillator section is running with the appropriate voltages set on nodes **120–124** so the tag oscillator runs at the slowest frequency allowable. The tag counter is reset on the rising edge of the base station steady, unmodulated signal, and the tag counter counts the clock pulses on line **102**. The tag counts the pulses until the next edge of the base station signal and compares the tag counter count to a certain preset number, for example, 8. If the tag counter count is greater than 8, the tag decides that the base station is sending a preamble detect signal, and readies itself for the next step. If the number of counts is less than 8 the tag resets the tag counter and begins again to wait for a long enough time t of steady, unmodulated RF. The waiting period prevents the oscillator from calibrating in the middle of a data transmission, as might occur if a tag enters the base station field during base station communication with another tag.

After the base station has sent a steady RF signal for the required length of time in step **805**, the base station in step **815** starts to send a steadily modulated signal where the RF is turned on and off at a frequency f_1. At the rising edge of the first modulated pulse, the tag starts the calibration procedure of step **820**, and for the next N pulses (where N is an integer) of the steadily modulated RF from the base station, the tag sets the calibration of the tag oscillator so that the tag oscillator frequency is set approximately to a certain multiple of the base station modulation frequency f_1. When the base station has sent a sufficient number of pulses in step **815** that the tag has had time to complete step **820**, the base station sends a particular modulation pattern called a "Start Delimiter Code" in step **825**. The start delnimter code optionally contains pulses that are "too long" in that the RF field is "on" for three times as long as would be the case when the base station were sending a steadily modulated RF signal with modulation frequency f_1. This "long pulse" technology is innovative in the field of RF tags. The tag receives the start delimiter code in step **830**, using the start delimiter code to check that that the tag oscillator frequency is indeed set correctly and that the tag is decoding valid base station data. Further, the receipt of the start delimiter code ensures that the tag matches the base station's place in the data stream If the start delimiter code is not received correctly, the tag returns to step **810**. The tag proceeds to the next step **840** of receiving the command sent by the base station. Meanwhile, the base station now transmits command data in step **835**. Such data could be instructions to the tag to write data to the tag memory, to read data from the tag memory and transmit the data to the base station, to set some tag state indicator, or for the tag to perform some other tag function which the particular tag may be able to perform. The tag receives the command data in step **840**, and decides in step **850** on the basis of the command data what to do. If the command data is garbled, the tag cannot understand what to do, and returns to step **810** to wait for another try. If the tag does understand the command data, the tag may write data to the tag memory in step **870** or transmit data to the base station in step **860**, as examples, and then the tag returns to step **810** to await further orders. During the writing of data to the tag memory **870** or transmitting data to the base station step **860**, the base station transmits full power in a steady unmodulated stream of RF power in order to supply power throughout the relatively slow E^2-PROM write operation. (If faster memory elements such as ferroelectric random access memory (FRAM) memory elements are used, the tag may write the memory at the same time as the data is received.) The base station receives any data sent from the tag in step **855** which takes place simultaneously with step **845**, and then takes further action as appropriate.

A flow chart **900** of the method of calibrating the tag oscillator is shown in FIG. **9**. The tag resets the tag oscillator

so that the tag oscillator frequency is the lowest possible frequency in step **910**. In the example given by FIG. **5***a* and FIG. **5***b*, all nodes **120–124** would be set high so that only low current charges capacitor section **106**. The most significant bit is then reset to 0 in step **920**. The local counter **200** is reset to zero on the rising edge of the steadily modulated RF field sent out by the base station in step **815** of FIG. **8**. (It is clear to one skilled in the art that falling edges could also be used, or any other regular transitions.) The local counter then counts pulses on line **102** in step **940** until the next rising edge of the steadily modulated RF field sent out from the base station. If the count value is greater than 8 (ie 9 or greater), the decision step **950** sends the system to step **960**, where the last bit which was reset to zero is set back to one. (The oscillator is running too fast, and has to be slowed down. Because the control devices are p-FETs in the embodiment described, a logic level **1** is used to turn them off.). If the count is less than 9, the oscillator is running slow, and the system skips from step **950** to **970** to reset the next significant bit to zero. If all the control bits have not been reset, the system then decides at step **980** to return to step **930** to measure again whether the oscillator is running fast or slow compared to the base station modulation frequency, and the process is repeated in order from the most significant bit to the least significant bit until all nodes **120 –124** in FIG. **5***a* are set correctly so that the tag oscillator frequency is just under 9 times the base station modulation frequency. Of course, it is clear to one skilled in the art that the count value could be more or less than 8 for the tag to calibrate the tag oscillator with respect to the base station modulation frequency. When all the bits have been reset (and possibly set again to 1), the system moves to step **990** and optionally reduces the tag oscillator frequency so that it is surely less than 9 times the base station modulation frequency.

Throughout the rest of the data stream, the settings on nodes **120–124** remain fixed. However, the phase reset signal **116** continues to be generated to maintain synchronization during the base station to tag data transmission.

Note that the phase reset signal **116** is not generated while the tag is writing data to the tag memory or while the tag is transmitting data to the base station. During these operations, the base station transmits unmodulated RF power, and the tag clock section **40** is free running at the calibrated frequency which is determined by the settings on nodes **120–124**.

It will be apparent to one skilled in the art that circuits equivalent to those disclosed herein may be used for the purposes stated herein. In particular, the equivalent n-FET and p-FET circuits are anticipated by the inventors.

We claim:

1. A passive radio frequency (RF) transponder (tag) for receiving an RF signal from a base station, comprising;

a tag antenna for receiving the RF signal fron the base station the RF signal having a carrier frequency;

a tag rectification power supply connected to the tag antenna;

a tag logic section and a tag memory section the tag logic section and the tag memory section receiving power only from the tag antenna through the tag rectification power supply;

a receiver section connected to the tag antenna; and

a tag oscillator connected to the receiver section, the tag oscillator having a plurality of possible discrete frequencies of oscillation, the tag oscillator having a tag oscillation frequency much less than the carrier frequency, the tag oscillator frequency used to determine a tag modulation frequency of an RF signal backscattered from the tag antenna, the tag oscillation frequency determined by the RF signal sent from the base station.

2. The RF tag of claim **1**, where the RF signal is modulated at a modulation frequency f_1, and the frequency of oscillation of the tag oscillator is determined by f_1.

3. The RF tag of claim **2**, where the RF signal is amplitude modulated at a modulation frequency f_1.

4. The RF tag of claim **2**, where the RF signal is frequency modulated at a modulation frequency f_1.

5. The RF tag of claim **2**, where the RF signal is phase modulated at a modulation frequency f_1.

6. The RF tag of claim **1**, wherein the tag oscillator further comprises;

a current source section;

a capacitor section, the capacitor section charged from the current source section;

a voltage comparator section, the voltage comparator section comparing the voltage across the capacitor section to a preset comparison voltage; and

a switch, the switch discharging the capacitor section when the voltage across the capacitor section reaches the preset comparison voltage.

7. The RF tag of claim **6**, where the current source section comprises a plurality of defined current sources, at least one of the plurality of defined current sources being controlled to charge the capacitor section in response to the RF signal sent from the base station.

8. The RF tag of claim **7**, where at least one of the defined current sources is a defined current transistor in series with a transistor switch.

9. The RF tag of claim **6**, where the capacitor section source comprises a plurality of capacitances connected in parallel, at least one of the plurality of capacitances being controlled to receive current or not to receive current from the current source section in response to the RF signal sent from the base station.

10. The RF tag of claim **6**, where the comparator section source further comprises a plurality of defined current sources for delivering current to a voltage comparison circuit, at least one of the plurality of defined current sources being controlled to deliver current in response to the RF signal sent from the base station.

11. The RF tag of claim **1**, where the tag oscillator uses less than 500 microamperes of current.

12. The RF tag of claim **11**, where the tag oscillator uses less than 1 microampere of current.

13. A method of setting a tag oscillation frequency of a tag oscillator of a passive RF tag comprising;

a) receiving an RF signal from a base station, and;

b) adjusting the tag oscillation frequency in response to the RF signal from the base station, wherein the tag oscillation frequency is much less than a carrier frequency of the RF signal, and wherein the tag oscillation frequency is used to determine a tag modulation frequency of an RF signal backscattered from the tag.

14. The method of setting an oscillation frequency of claim **13**, where the RF signal is modulated at a modulation frequency f_1 and the oscillation frequency is set as a function of f_1.

15. The method of claim **14**, where the RF signal is amplitude modulated at a modulation frequency f_1.

16. The method of claim **14**, where the RF signal is frequency modulated at a modulation frequency f_1.

17. The method of claim **14**, where the RF signal is phase modulated at a modulation frequency f_1.

18. The method claim 14, where the tag counts the number of tag oscillator pulses in one period of the base station modulation frequency, and adjusts tag oscillator frequency so that the number is approximately equal to a preset number.

19. A method of setting an oscillation frequency of a tag oscillator of a passive RF tag, where the tag adjusts the oscillator frequency according to the following steps;

a) setting the tag oscillator so that the tag oscillation frequency is the lowest possible frequency by setting all control bits equal to one;

b) resetting the most significant bit equal to zero;

c) resetting a local counter of tag oscillator pulses on a rising edge of the steadily modulated RF field sent out by the base station;

d) counting pulses of the tag oscillator until the next rising edge of the steadily modulated RE field sent out from the base station;

e) if the count value is greater than a preset number, resetting the local counter, setting the last bit reset to one, resetting the next significant bit to zero, and returning to step (c);

f) if the count value is less than the preset number, resetting the local counter, resetting the next significant bit to zero, and returning to step (c); and

g) continuing until all control bits have been set or reset and the count value is approximately equal to the preset number.

20. The method claim 19, where the tag further adjusts the oscillator frequency in the additional step;

h) slowing the tag oscillator so that the count value is definitely less than the preset number, and definitely more than the preset number minus one.

21. The method claim 19, where the tag further adjusts the tag oscillator in the additional step of; resetting the tag oscillator phase on the rising edge of the steadily modulated RF field sent out by the base station.

22. A system for sending and receiving modulated RF signals, comprising;

a base station for sending modulated RF signals, the RF signals having a carrier frequency; and

at least one passive RF tag for receiving the RF signals, the RF tag comprising a tag antenna for receiving the RF signal from the base station, a tag receiver section connected to the tag antenna; and a tag oscillator connected to the tag receiver section, the tag oscillator having a tag oscillation frequency much less than the carrier frequency, the tag oscillation frequency used to determine the a modulation frequency of an RF signal backscattered from the tag antenna, the tag oscillator frequency determined by the Rf signals sent by the base station.

23. The system of claim 22, where the base station sends RF signals modulated at a modulation frequency f_1, and the frequency of oscillation of the tag oscillator is determined by the modulation frequency f_1.

24. The system of claim 23, where the RF signal is amplitude modulated at a modulation frequency f_1.

25. The system of claim 23, where the RF signal is frequency modulated at a modulation frequency f_1.

26. The system of claim 23, where the RF signal is phase modulated at a modulation frequency f_1.

27. The system of claim 22, where the base station further comprises a computer for receiving and sending data from and to the tag.

28. A passive radio frequency (RF) transponder (tag) for receiving an RF signal from a base station, comprising;

a tag antenna for receiving the RF signal from the base station, the RF signal having a carrier frequency;

a receiver section connected to the tag antenna;

a tag rectification power supply connected to the tag antenna;

a tag logic section and a tag memory section, the tag logic section and the tag memory section receiving power only from the tag antenna through the tag rectification power supply; and

a tag oscillator connected to the receiver section, the tag oscillator having a tag oscillation frequency much less than the carrier frequency, the tag oscillation frequency used to determine a tag modulation frequency of an RF signal backscattered from the tag antenna, the tag oscillation frequency determined by the RF signal sent from the base station.

* * * * *

EXHIBIT F

US005995019A

United States Patent [19]

Chieu et al.

[11] Patent Number: 5,995,019

[45] Date of Patent: *Nov. 30, 1999

[54] **METHOD FOR COMMUNICATING WITH RF TRANSPONDERS**

[75] Inventors: **Trieu Can Chieu**, Scarsdale; **Thomas Anthony Cofino**, Rye; **Harley Kent Heinrich**, Brewster, all of N.Y.; **Paul Jorge Sousa**, Peabody, Mass.; **Li-Cheng Richard Zai**, Ossining, N.Y.

[73] Assignee: **Intermec I.P. Corp**

[*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: **09/111,096**

[22] Filed: **Jul. 6, 1998**

Related U.S. Application Data

[63] Continuation of application No. 08/720,598, Sep. 30, 1996, Pat. No. 5,777,561.

[51] **Int. Cl.**[6] **H04Q 1/00**

[52] **U.S. Cl.** **340/825.54**; 342/42

[58] **Field of Search** 340/825.54, 572.1, 340/825.52; 342/42

[56] **References Cited**

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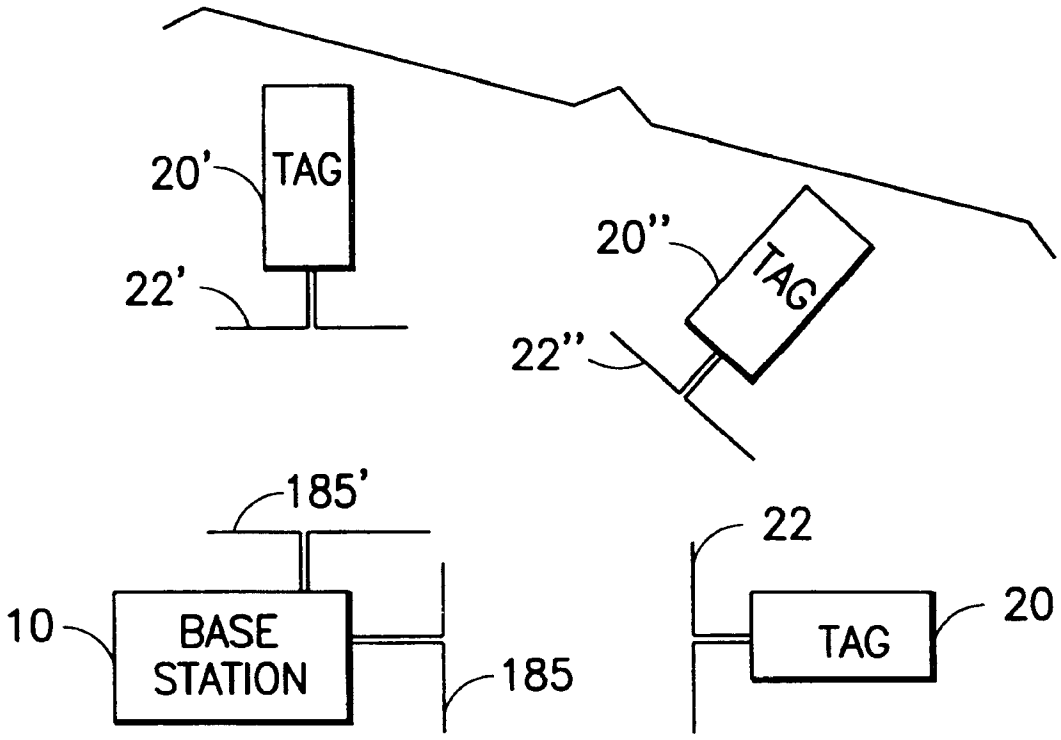
Primary Examiner—Brian Zimmerman

Attorney, Agent, or Firm—R.T. Hodgson

[57] **ABSTRACT**

A method of selecting groups of radio frequency RF transponders (tags) for communication between a base station and the tags. The tags are selected into groups according to a physical attribute of the signal sent by the tags to the base station, or according to the physical response of the tags to a physical attribute of the signal sent from the base station to the tags. Communication with the tags is thereby simplified, and the time taken to communicate with the first tag is markedly reduced.

18 Claims, 7 Drawing Sheets



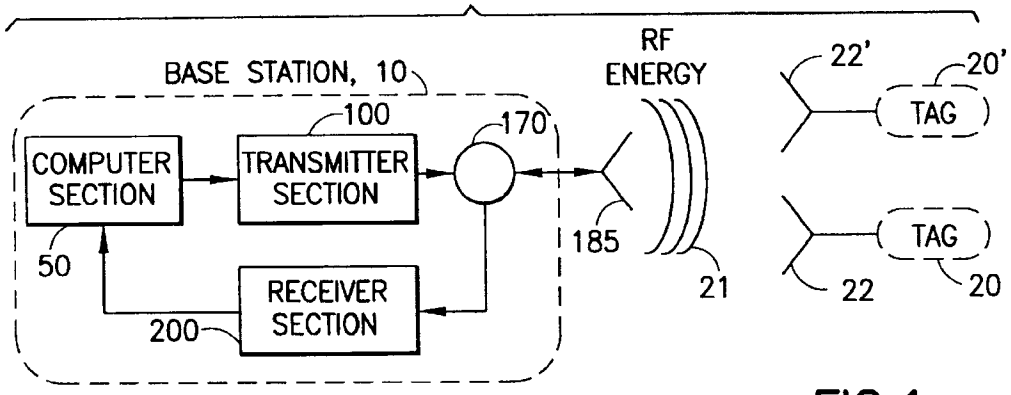


FIG.1

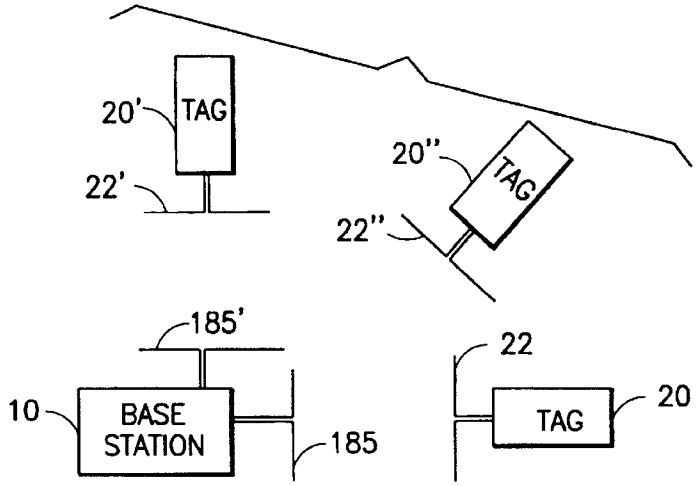


FIG.2

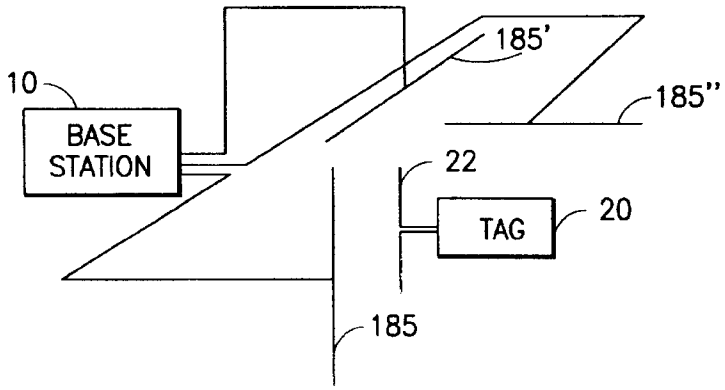


FIG.3

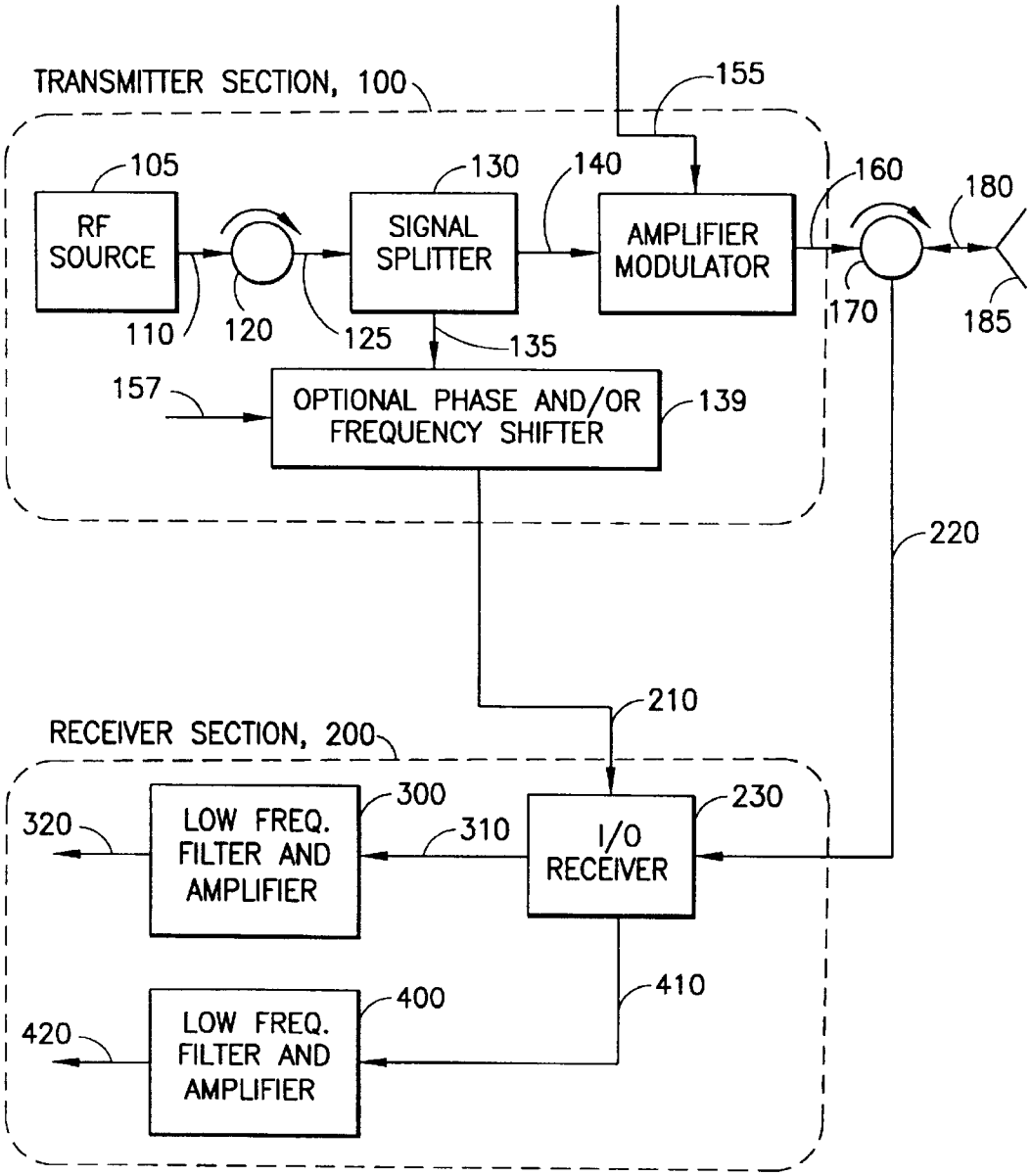

TRANSMITTER SECTION, 100
155
105
130
140
160
180
RF SOURCE
SIGNAL SPLITTER
AMPLIFIER MODULATOR
110
120
125
135
170
185
157
OPTIONAL PHASE AND/OR FREQUENCY SHIFTER
139
220
210
RECEIVER SECTION, 200
300
230
320
310
LOW FREQ. FILTER AND AMPLIFIER
I/O RECEIVER
410
400
420
LOW FREQ. FILTER AND AMPLIFIER

FIG.4

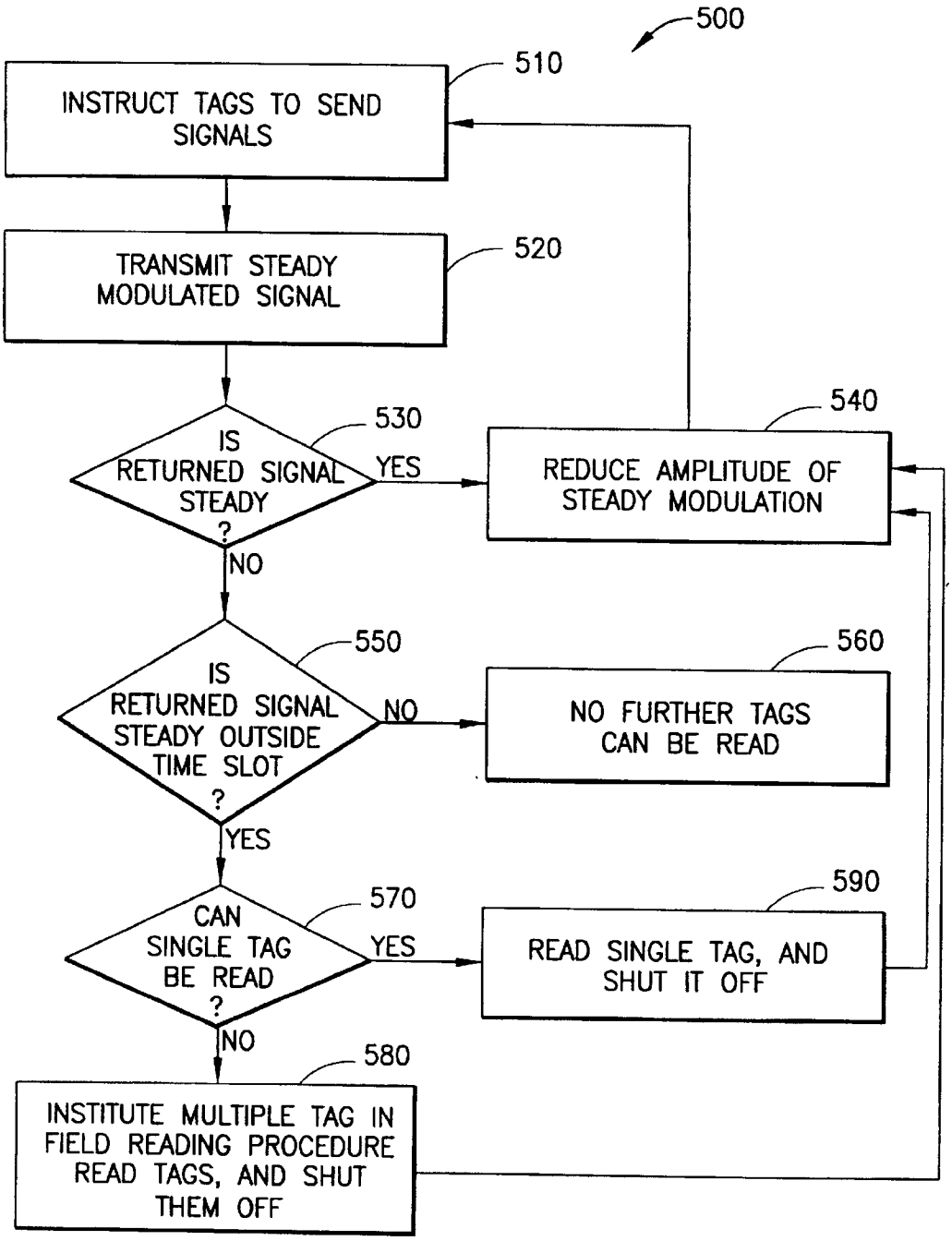

500
510
INSTRUCT TAGS TO SEND SIGNALS
520
TRANSMIT STEADY MODULATED SIGNAL
530
IS RETURNED SIGNAL STEADY ?
YES
540
REDUCE AMPLITUDE OF STEADY MODULATION
NO
550
IS RETURNED SIGNAL STEADY OUTSIDE TIME SLOT ?
NO
560
NO FURTHER TAGS CAN BE READ
YES
570
CAN SINGLE TAG BE READ ?
YES
590
READ SINGLE TAG, AND SHUT IT OFF
NO
580
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE READ TAGS, AND SHUT THEM OFF

FIG.5

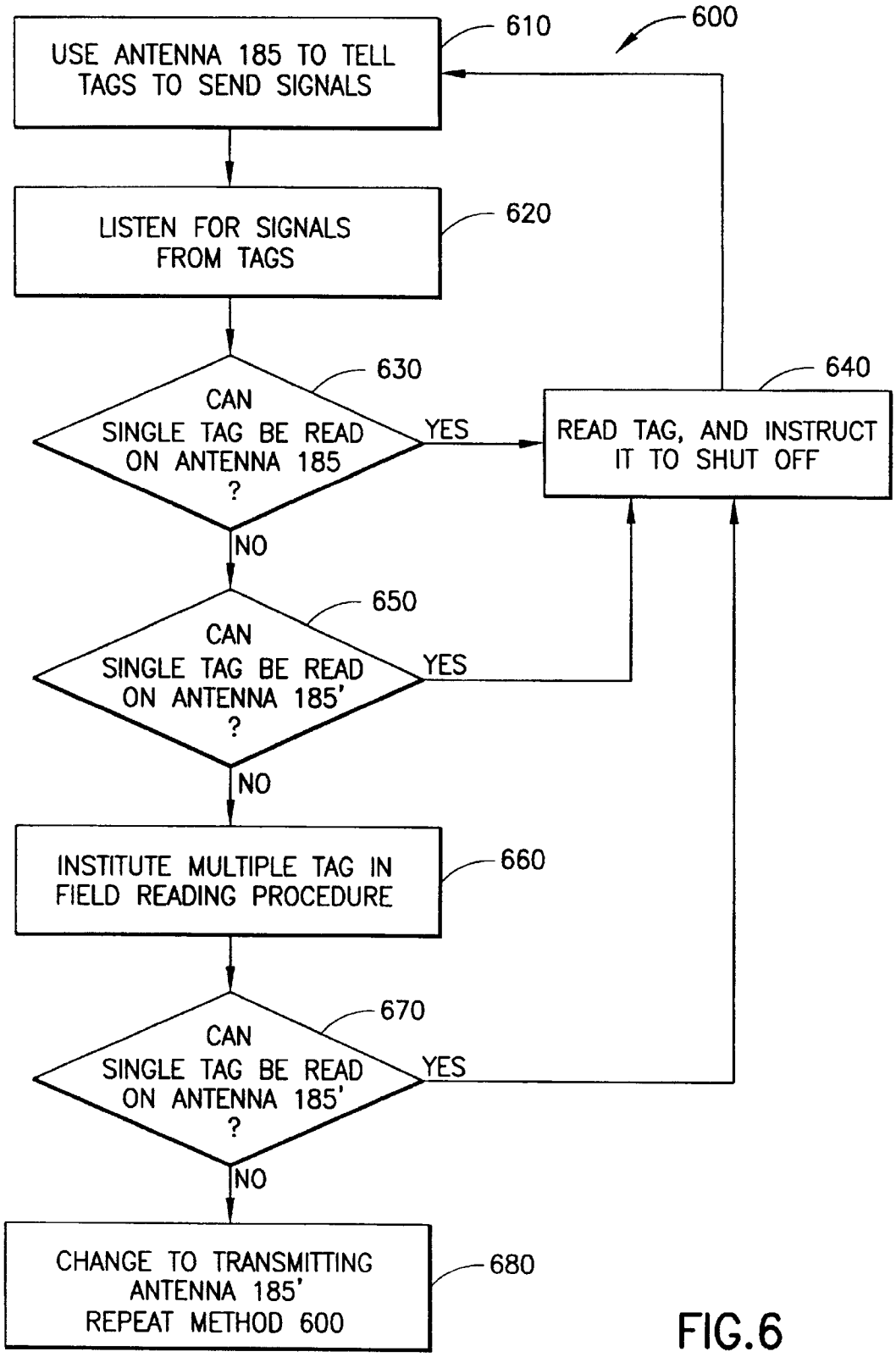

600
610
USE ANTENNA 185 TO TELL TAGS TO SEND SIGNALS
620
LISTEN FOR SIGNALS FROM TAGS
630
CAN SINGLE TAG BE READ ON ANTENNA 185 ?
YES
640
READ TAG, AND INSTRUCT IT TO SHUT OFF
NO
650
CAN SINGLE TAG BE READ ON ANTENNA 185' ?
YES
NO
660
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
670
CAN SINGLE TAG BE READ ON ANTENNA 185' ?
YES
NO
680
CHANGE TO TRANSMITTING ANTENNA 185' REPEAT METHOD 600

FIG.6

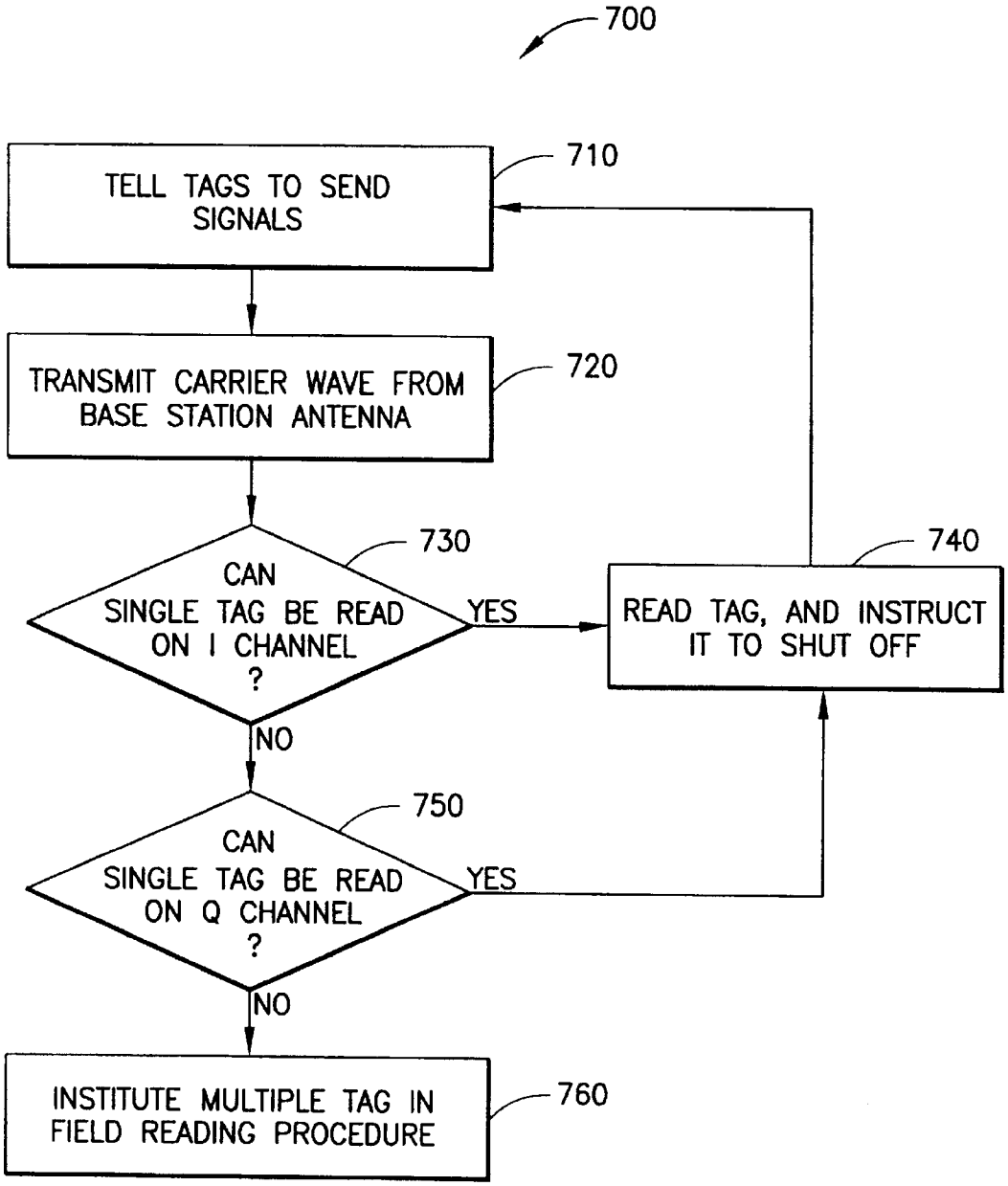

700
TELL TAGS TO SEND SIGNALS
710
TRANSMIT CARRIER WAVE FROM BASE STATION ANTENNA
720
CAN SINGLE TAG BE READ ON I CHANNEL ?
730
YES
READ TAG, AND INSTRUCT IT TO SHUT OFF
740
NO
CAN SINGLE TAG BE READ ON Q CHANNEL ?
750
YES
NO
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
760

FIG.7

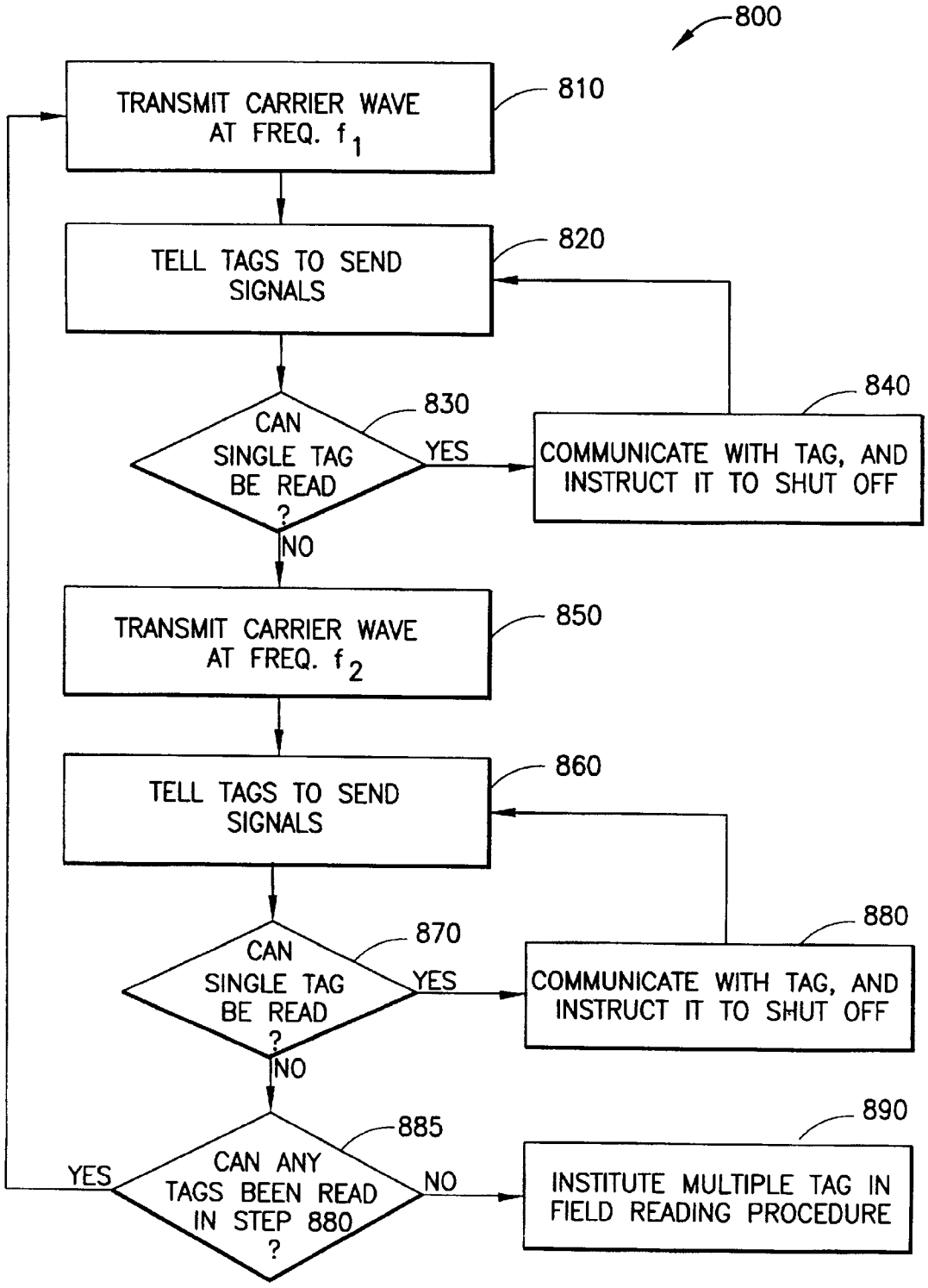

800
TRANSMIT CARRIER WAVE AT FREQ. f_1
810
TELL TAGS TO SEND SIGNALS
820
CAN SINGLE TAG BE READ ?
830
YES
COMMUNICATE WITH TAG, AND INSTRUCT IT TO SHUT OFF
840
NO
TRANSMIT CARRIER WAVE AT FREQ. f_2
850
TELL TAGS TO SEND SIGNALS
860
CAN SINGLE TAG BE READ ?
870
YES
COMMUNICATE WITH TAG, AND INSTRUCT IT TO SHUT OFF
880
NO
CAN ANY TAGS BEEN READ IN STEP 880 ?
885
YES
NO
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
890

FIG.8

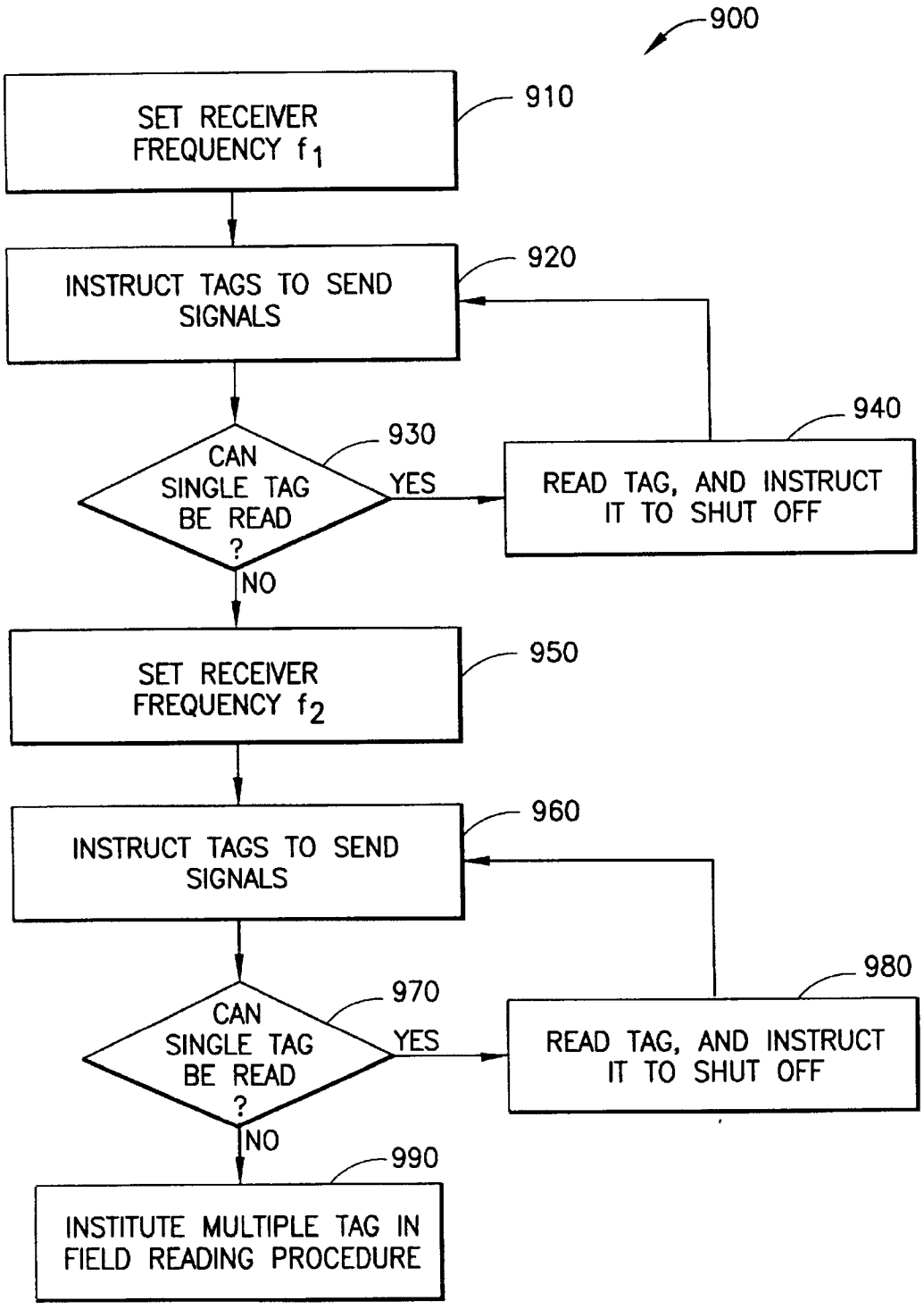

900
SET RECEIVER FREQUENCY f_1
910
INSTRUCT TAGS TO SEND SIGNALS
920
CAN SINGLE TAG BE READ ?
930
YES
READ TAG, AND INSTRUCT IT TO SHUT OFF
940
NO
SET RECEIVER FREQUENCY f_2
950
INSTRUCT TAGS TO SEND SIGNALS
960
CAN SINGLE TAG BE READ ?
970
YES
READ TAG, AND INSTRUCT IT TO SHUT OFF
980
NO
INSTITUTE MULTIPLE TAG IN FIELD READING PROCEDURE
990

FIG.9

METHOD FOR COMMUNICATING WITH RF TRANSPONDERS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of application Ser. No. 08/720,598, filed Sep. 30, 1996, now U.S. Pat. No. 5,777,561, issued Jul. 7, 1998.

FIELD OF THE INVENTION

The field of the invention is the field of Radio Frequency (RF) Transponders (RF Tags), wherein a Base Station sends power and information to one or more RF Tags which contain logic and memory circuits for storing information about objects, people, items, or animals associated with the RF Tags. The RF Tags can be used for identification and location (RID Tags) of objects and to send information to the base station by modulating the load on an RF Tag antenna.

BACKGROUND OF THE INVENTION

RF Tags can be used in a multiplicity of ways for locating and identifying accompanying objects, items, animals, and people, whether these objects, items, animals, and people are stationary or mobile, and transmitting information about the state of the of the objects, items, animals, and people. It has been known since the early 60's in U.S. Pat. No. 3,098,971 by R. M. Richardson, that electronic components on a transponder could be powered by radio frequency (RF) power sent by a "base station" at a carrier frequency and received by an antenna on the tag. The signal picked up by the tag antenna induces an alternating current in the antenna which can be rectified by an RF diode and the rectified current can be used for a power supply for the electronic components. The tag antenna loading is changed by something that was to be measured, for example a microphone resistance in the cited patent. The oscillating current induced in the tag antenna from the incoming RF energy would thus be changed, and the change in the oscillating current led to a change in the RF power radiated from the tag antenna. This change in the radiated power from the tag antenna be picked up by the base station antenna and thus the microphone would in effect broadcast power without itself having a self contained power supply. In the cited patent, the antenna current also oscillates at a harmonic of the carrier frequency because the diode current contains a doubled frequency component, and this frequency can be picked up and sorted out from the carrier frequency much more easily than if it were merely reflected. Since this type of tag carries no power supply of its own, it is called a "passive" tag to distinguish it from an active tag containing a battery. The battery supplies energy to run the active tag electronics, but not to broadcast the information from the tag antenna. An active tag also changes the loading on the tag antenna for the purpose of transmitting information to the base station.

The "rebroadcast" of the incoming RF energy at the carrier frequency is conventionally called "back scattering", even though the tag broadcasts the energy in a pattern determined solely by the tag antenna and most of the energy may not be directed "back" to the transmitting antenna.

In the 70's, suggestions to use tags with logic and read/write memories were made. In this way, the tag could not only be used to measure some characteristic, for example the temperature of an animal in U.S. Pat. No. 4,075,632 to Baldwin et. al., but could also identify the animal. The antenna load was changed by use of a transistor.

Prior art tags have used electronic logic and memory circuits and receiver circuits and modulator circuits for receiving information from the base station and for sending information from the tag to the base station.

The continuing march of semiconductor technology to smaller, faster, and less power hungry has allowed enormous increases of function and enormous drop of cost of such tags. Presently available research and development technology will also allow new function and different products in communications technology.

U.S. Pat. No. 5,214,410, hereby incorporated by reference, teaches a method for a base station to communicate with a plurality of Tags . The tags having a particular code are energized, and send a response signal at random times. If the base station can read a tag unimpeded by signals from other tags, the base station interrupts the interrogation signal, and the tag which is sending and has been identified shuts down. The process continues until all tags in the field have been identified. If the number of possible tags in the field is large, this process can take a very long time. The average time between the random responses of the tags must be set very long so that there is a reasonable probability that a tag can communicate in a time window free of interference from the other tags.

RELATED APPLICATIONS

Copending patent applications assigned to the assignee of the present invention and hereby incorporated by reference, are:

- Ser. No. 08/303,965, filed Sep. 9, 1994 entitled RF Group Select Protocol, by Cesar et al, now U.S. Pat. No. 5,670,037;
- Ser. No. 08/304,340, filed Sep. 9, 1994 entitled Multiple Item RF ID protocol, by Chan et al, now U.S. Pat. No. 5,550,547;
- Ser. No. 08/521,898, filed Aug. 31, 1995 entitled Diode Modulator for RF Transponder by Friedman et al, now U.S. Pat. No. 5,606,323;

application submitted Aug. 9, 1996, entitled RFID System with Broadcast Capability by Cesar et al; and

- application submitted Jul. 29, 1996 entitled RFID transponder with Electronic Circuitry Enabling and Disabling Capability, by Heinrich et al.

These applications teach a communications protocol whereby a base station communicates to a plurality of tags by polling the tags and shutting down tags in turn until there is just one left The information is then exchanged between the base station and the one tag, and then the one tag is turned off. The unidentified tags are then turned on, and the process is repeated until all the tags have the communication protocol completed. Typical protocols requires a time which is not linearly proportional to the number of tags in the field More tags take a longer time per tag than fewer tags. If the tags can be selected into groups in some way, each group can be dealt with in a shorter time per tag, and the time taken to communicate with the first tag is markedly shortened.

SUMMARY OF THE INVENTION

The method of the present invention is a method of selecting groups of RF tags for a communication protocol comprising selecting a plurality of groups of tags according to a physical attribute of the signal sent by the tags to the base station, or selecting the groups according to the physical response of the tags to a physical attribute of the signal sent from the base station to the tags, and communicating

with the tags in each group. A single tag may be a member of one or more groups. Some groups may have no members. The most preferred embodiment of the invention is the method of selecting groups on the basis of the physical signal strength of the RF signal received from the tags by the base station. The tags have greater or less received signal strength depending on the distance to the base station antenna, the relative orientation of the tag and the base station antennas, and the local conditions of reflectors and absorbers of radiation around the tag. The base station may also select groups of tags according to the polarization or the phase of the returned RF signal, the RF carrier or Doppler shifted RF carrier or modulation frequency sent by the tags, or any another physical signal from the tags. The base station may also select groups of tags according to the physical response of the tags to the polarization, phase, carrier frequency, modulation frequency, or power of the RF signal sent by the base station. The communication protocol can be carried out simultaneously or sequentially with the selected groups. The physical characteristics used to group the tags can be measured simultaneously or sequentially. Different groups may be selected by taking the union, the intersection, or other combinations of the various groups of tags selected according to the different physical attributes. The tag group selection parameters may also include selecting groups by software, i.e. by selecting the groups according to information stored on the tag.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a generalized diagram of a base station communicating to one or more tags.

FIG. **2** is a diagram of a base station having two antennas for receiving information about the polarization of the signal sent by a tag.

FIG. **3** is a diagram of a base station having three antennas for receiving information about the polarization and phase position of the signal sent by a tag.

FIG. **4** is a diagram of a base station circuit which can select the strongest signals from signals sent by a plurality of tags.

FIG. **5** is a flow chart of the most preferred embodiment of the invention.

FIG. **6** is a flow chart of a preferred embodiment of the invention.

FIG. **7** is a flow chart of a preferred embodiment of the invention.

FIG. **8** is a flow chart of a preferred embodiment of the invention.

FIG. **9** is a flow chart of a preferred embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** sketches abase station **10** sending RF energy **21** and information to one or more tags **20**. The tags **20** may have varying distances from the base station, and the tag antennas **22** may be in any orientation with respect to the base station antenna. The base station comprises a transmitter section **100**, a computer section **50**, a circulator **170**, a receiver section **200**, and one or more antennas **185**.

FIG. **2** depicts a base station **10** which can group the tags **20** into groups on the basis of polarization of the RF radiation back scattered to the base station **10**. The base station **10** has two perpendicular antennas **185** and **185'** communicating with three tags **20**, **20'**, and **20"**. The antennas **185** and **185'**, and **22**, **22'** and **22"** are depicted as simple dipole antennas which transmit linearly polarized radiation with the polarization substantially parallel to the antennas. In the diagram shown, antenna **185** may communicate well with the tag **20** having an antenna **22** parallel to antenna **185**, less well with the antenna **22"** which is shown having a 45 degree orientation with respect to antenna **185**, and not at all with the tag with a perpendicular antenna **22'**. The groups are first selected on the a basis of the response of the tags to the polarization of the signal sent out from the base station. In this example, two groups are selected: those tags which respond to the particular polarization, and those tags which do not respond. In the embodiment depicted in FIG. **2**, a signal sent out from antenna **185** brings responses from tag **20** and from tag **20"** to antenna **185**, and from tag **20"** alone to antenna **185'**. The tag antenna **22'** may not receive power from the perpendicular antenna **185**, and so tag **20'** remains silent. The tags are then further selected into subgroups according to the polarization of the returned signal. Thus, three groups of tags are selected by this method in this example, tag **20'** is in one group of "silent" tags, tag **20"** is in the group which is picked up by antenna **185'** because the polarization of the signal from tag **20"** can be detected by antenna **185'**, and tags **20** and **20"** are in the group with polarization components which may be picked up by antenna **185**. Communication with each of the two "non silent" groups in turn or in parallel simplifies and speed the communication protocol. In particular, the time taken to communicate with the first tag is markedly reduced. In the example given above, the signal returned to antenna **185'** is the signal from only a single tag **20"**, and that tag can return the tag identification number while the antenna **185** receives signal signifying more than one tag in the field. The tag **20"** may then be turned off for the duration of the communication procedure, and the process repeated to identify and shut down tag **20**. The sending antenna is then switched to antenna **185'**, and the remaining tag **20'** is identified. While a linear polarization scheme is shown as an example, it is clear to one skilled in the art that circularly polarized signals could also be used with good effect. The exact orientations of the antennas are also not critical to the invention, as long as there is a difference in the sensitivity of the antennas to the polarization of the RF signals sent by the tags. A single base station antenna could be used, as long as the polarization characteristics of the single base station antenna could be changed by the base station or by other means.

FIG. **3** shows a base station **10** with more than two dipole antennas **185**, **185'**, and **185"**. In this example, each antenna axis is mutually orthogonal so that the orientation of the linearly polarized backscattering from dipole antennas **22** in the field can be measured and the tags selected into groups for the communication procedure.

FIG. **4** shows a block diagram for circuitry which can allow the base station to select a group of tags by the signal strength received at the base station. The equipment for implementing the method of the most preferred embodiment of the invention uses five sections of the base station **10**: a computer section **50**, a transmitter section **100**; a receiver section **200**; a hybrid coupling device **170**; and an antenna **185**. The computer section may be a relatively unsophisticated circuit for controlling the transmitter and for receiving signals from the receiver, or it could include highly sophisticated workstations for interrogating and writing information to the tags. The transmitter section **100**, under control of the computer section **50**, sends a signal of the appropriate amplitude and frequency (which may or may not be modulated) to the hybrid **170**, which sends the (modulated)

signal to the antenna **185**. The preferred modulation for communication to and from the tags is amplitude modulation, but it may be either frequency or phase modulation. The antenna **185** both sends out the RF carrier frequency which may or may not be modulated, and captures the signals radiated by the tags **20**. The antenna **185** captures the signals radiated by the tags and sends the signals back to the hybrid **170**, which sends the signals to the receiver section **200**. The receiver section down converts and extracts the modulated signal from the carrier, and converts all the modulation energy it receives to a baseband information signal at its output. In the most preferred embodiment, the receiver has two outputs in quadrature called I (in phase with the transmitted carrier) and Q (quadrature, 90 degrees out of phase with the carrier). However, various embodiments of the invention have just one output. The hybrid element **170** connects the transmitter and receiver to an antenna while simultaneously isolating the transmitter and the receiver from each other. That is, the hybrid allows the antenna to send out a strong signal from the transmitter while simultaneously receiving a weak backscattered reflection. The strong transmitted signals being sent into the antenna must be eliminated from the receiver by the hybrid.

The transmitter section depicted by block **100** provides the energy and frequency signals for the transmitter carrier and the receiver down converter, and the amplified and modulated signal **160** which may be sent by the antenna **185**. The RF source **105** of signal **110** is usually isolated by an element **120** between the carrier signal source **105** and the rest of the circuit which avoids coupling problems of coupling reflections back to the RF source. The isolation element **120** is usually a circulator with one port terminated by a resistor. The isolated carrier signal **125** is split into two paths in a signal splitter element **130**. Most of the energy **140** goes to an amplifier modulator element **150**, while signal **135** takes a small signal to the receiver section depicted by block **200**. An optional phase and/or frequency shifter element **139** may be included between the signal splitter **130** and the receiver section **200** to provide control by the computer section **50** over line **157** of the reference phase and frequency signal **210** which the receiver section uses in detecting the signals from the tags. The phase and or frequency shifter **139** may send out signals differing by a small amount in frequency from the signal **110** sent out from the RF source **105**, or it may send out harmonics of the signal. In the amplifier modulator section **150**, the carrier frequency is amplified and modulated by a signal **155** controlled by computer section **50**. A preferred embodiment has a carrier frequency greater than 400 MHZ. A more preferred embodiment has a carrier frequency greater than 900 MHZ. The most preferred embodiment uses a carrier frequency of from 2.3 to 2.5 Ghz, and this signal is amplitude modulated at 20–60 kHz. In the preferred embodiment, a direct modulation of the carrier frequency is depicted However, an up converter of multiple frequencies may also be used. This modulated signal **160** enters the hybrid element **170** and is passed over lead **180** to the antenna **185**. A modulator signal is applied at **155** into the modulator **150** to give a modulation which may be amplitude, frequency or phase modulation. The most preferred embodiment is amplitude modulation.

In the receiver section **200**, the received signal from the antenna **185** travels along lead **180** and enters the hybrid **170** which directs the signal along **220** to the receiver section depicted by block **200**. This signal comprises signals sent by the tags, which modulate the carrier frequency at a frequency of; for example, 40 KHz, and the reflected unmodulated transmitter carrier signal reflected from the antennas or other reflectors in the field. The antenna will never be perfectly matched to the transmitter, and will reflect a signal which is about 20 dB down from the signal transmitted by the antenna. Of course, the carrier signals reflected by the tags, and the various reflections of the transmitted signal, will be much weaker than the signal transmitted from the antenna. The receiver structure **230** of the most preferred embodiment here is a direct down conversion I and Q system where the mixing frequency signal **210** is generated by the source **105** and is the only send-out by the transmitter. The single down conversion system receiver removes the carrier frequency signal and generates two baseband signals which have frequencies in the 40 KHz region in quadrature **310** and **410**. These signals are filtered and amplified by means of signal processing in elements **300** and **400**. The signals **320** and **420** are passed to the computer section **50** for further processing.

The hybrid component **170** is typically a circulator. It passes signals from 160 to 180, from 180 to 220, from 220 to 160 but not the other way around. Hence the transmitter is isolated from both the small amount of modulated carrier reflected by the antenna **185** (20 dB down typically) and the circulator (20 dB leakage typically). The receiver is isolated from the large signal sent from the transmitter **100** to the antenna **185**, and receives about −20 dB signal from leakage from the circulator 170 and a further −20 dB of signal from the reflection from the antenna.

Of course, when the base station modulates the carrier signal to transfer information from the base station to the tags, the reflected modulated signals from the antenna and the leakage from the circulator will swamp out any signals sent by the tags. In the prior art the tags communicate in a time period when there is no modulation of the carrier signal transmitted from the base station, or the tags communicate at a different carrier frequency than that transmitted by the base station, so that the receiver can pick out the modulated signals from the tags from all the reflections and leakages of the carrier signals. The present invention allows simple discrimination of signals by the tag to the base station sent as modulation of the base station carrier frequency, or as modulations of another frequency, from one or more tags, and allows the tags to be sorted in groups determined by the tag signal strength received at the base station.

The most preferred embodiment of the present invention is a method to sort the tags into groups by sending a steady, weak signal modulation at the communication modulation frequency to the tags in the time period where the prior art sends an unmodulated carrier signal so that the tags may communicate back to the base station. The steady, weak modulation frequency is not strong enough to influence the tag, but is strong enough so that the steady, weak modulated signals reflected from the antenna **185** and leaked around the hybrid **170** can be measured by the receiver and can be used to set a level for discriminating amongst the tag signals. In the most preferred embodiment, the communication to the tags is carried out by a 100% amplitude modulation of the carrier frequency at a 20–60 Khz frequency. The preferred protocol for the tags to detect such information is a 50 dB on/off ratio, but this is not necessary to the invention. Any modulation of the carrier frequency which can conceivably be used for communication between the tags and the base station can be used. Such modulations as frequency modulation and phase modulation are well known in the art. In the present invention, a modulation amplitude less than that used to communicate with the tags is impressed on the outgoing carrier wave. The mismatch at the antenna will

always cause that signal to be reflected and to be present at the receiver. This signal is detected at the receiver and is used to establish a deterministic signal floor. As backscattered modulated signals are received and are stronger than this coupling signal, the received back scattered signal dominates the receiver. Hence, a high sensitivity receiver may be used with a forced coupled modulation from the transmitter as its signal noise floor, and behave in a predictable manner between the conditions of no tags in the field, a single tag in the field, multiple tags in the field, and interference. Furthermore, by varying the modulation strength of the weak, modulated signal, the returned signal strength of signals from the tags required to overcome the coupled modulator signal is increased or decreased thereby allowing the base station to select a group of tags based on the returned signal strength.

FIG. **5** depicts a flow chart **500** of the most preferred method for selecting groups of tags and communicating with the tags in each group. A modulation frequency of 40 Khz is chosen as an example. At step **510**, the base station transmits a modulated signal to the base station antenna, and hence to the tags, instructing the tags to respond and return a modulated signal in a time period (time slot) defined by the tag communication protocol. At step **520**, the base station transmits a carrier wave to the base station antenna The carrier wave has a steady 40 Khz amplitude modulation which is less than that required to communicate with the tags. The base station measures the 40 KHZ modulation received from the base station antenna in the time slot defined by the tag communication protocol. If the modulated signal received by the receiver **200** is steady in step **530**, the reflected modulated signal and leakage is greater than any signals received from tags, which would send an unsteady modulated signal. The base station then reduces the amplitude of the steady modulated signal in step **540** and the system returns to step **510**. If the modulated signal is not steady in step **530**, the base station checks at step **550** to see whether the modulated signal returned is steady outside the time slot defined by the tag communication protocol. If the modulated signal is unsteady when no tags are supposed to be sending signals, the unsteady signal is noise, and the receiver can not distinguish between signals sent by the tags and the noise. No tags are in reading position in the field, and the protocol is ended in step **560**. If however the modulated signal is steady outside the time slot, and unsteady in the time slot, one or more tags in the field are sending signals. These signals are stronger than the steady modulated signals received from the reflected steadily modulated carrier wave. If a single tag is in the field, and can be read at step **570**, the single tag is read and instructed to shut off, at step **590**, and the system is returned to step **540** to reduce the steady modulation and return to the beginning step **510** to try to find tags with less signal strength. If more than one tag is in the field and the tag signals interfere with each other so that they can not be read at step **570**, a multiple tag reading protocol is instituted in order to read the multiple tags at step **580**. The tags are read using the multiple tag reading protocol, and ordered to shut down, and the system is returned to step **540** to reduce the steady modulation and return to the beginning step **510** to try to find the group of tags with less signal strength than the first group.

Step **550** is preferably taken after step **530**, but step **550** may optionally be taken between steps **570** and **580** or after step **580** if no tags are read by the multiple tag reading procedure.

The most preferred embodiment of the invention uses a protocol in which the tags are commanded to return an identification signal in a particular time slot, but the same invention may be used where the tags are commanded to return information in any defined time periods.

While the preferred embodiment uses the naturally occurring reflections from the base station antenna **185** and leakage from the hybrid **170** to introduce the noise floor signal into the receiver **200**, many other means of introducing this signal to the receiver are possible to one skilled in the art. As an example, the steady 40 Khz modulation could be summed with the signals from the I/Q demodulator coming on lines **310** and **410**, or indeed a specially constructed device analogous to a two input I/Q demodulator could be constructed to accept the steady 40 Khz comparison signal from an outside source.

Additional embodiments of the invention include further subdividing the groups selected by the above method on the basis of the phase and/or polarization of the signals returned to the base station, as well as other physical or software group selection criteria.

A preferred embodiment of the invention is to select tags on the basis of the returned polarization of the signals. In the embodiment shown in FIG. **2**, groups of tags with antennas which return a linear polarization which is polarized more parallel to one or the other of the two dipole antennas **185** or **185'** sketched in FIG. **2** are selected. Returned signals from the two antennas are processed in parallel by two sets of receiver circuitry like that shown in FIG. **4**. The tags are interrogated by transmitting the modulated carrier signal from first one antenna **185**, then the other antenna **185'**, and four channels of signals (the I and Q channels received from each antenna) may be processed in parallel or in sequential fashion. This set up would select the tags into 8 groups, which of course may be further selected and grouped on the basis of the received signal strength or any other physical or software attribute.

FIG. **6** depicts a flow chart **600** of the preferred method of selecting groups of tags on the basis of the polarization of the signals returned to the base station. As an illustrative example, a base station comprising 2 antennas which are sensitive to different polarizations, such as depicted in FIG. **2**, is chosen. However, the number of antennas and whether the polarization is linear, circular, or some combination of the polarizations may be chosen at will by one skilled in the art. Step **610** uses antenna **185** to send a signal to the tags instructing the tags to return a signal in the time slot determined by the communication protocol. The antenna **185** is then used to listen for signals from the tags in the time slot where the tags return signals in step **620**. Signals retuning from antenna **185** are analysed in step **630** to see if the base station can read the signal. If the signal is returned from a single tag, the base station communicates with the single tag in step **640**, and instructs the tag to shut itself down for the remainder of the communication protocol, or until it is specifically instructed to start returning signals again. The system is then returned to step **610** to look for more tags. If the signal returned by the tags to antenna **185** can not be read, either because there are no tags in the field in a position to be read by antenna **185** or because there multiple tags trying to communicate at the same time, the system may then try to read a single tag communicating to antenna **185'** in step **650**. If a single tag is successfully read, the system reads the tag at step **640**, shuts the tag down, and returns to the beginning step **610** to try to read again the tags which may be tying to communicate to antenna **185**. Since there is now one fewer tag in the field, a tag may now be read at step **630** on antenna **185**. If a single tag can not be read in step **650**, a multiple tag in the field reading procedure is

instituted in step **660**. Steps **630** and **650** may be taken either sequentially or simultaneously, if two receivers are connected to the two antennas. If tags are read using one antenna in step **660**, the system decides in step **670** to communicate with the tags and turn them off and the system returns to step **610** to try to read a single or multiple tag from the other antenna If the multiple tag reading procedure does not read any tags from either antenna in stop **660**, the system may switch transmitting antennas in step **680**, so that the commands and carrier wave are transmitted to antenna **185'** instead of antenna **185**. The method **600** of the invention can then be used to identify and select other groups not found in the first application of method **600**. Alternatively, the system may switch transmitting antennas between steps **650** and **660** to try to find, communicate with, and shut off single tags.

Another antenna perpendicular to the two antennas shown in FIG. **2**, which is placed remotely from the base station as shown in FIG. **3** allows all combinations of linear polarized backscattering to be discriminated and allows the selecting of groups based on all polarizations of the received signal.

The three antennas **185**, **185'**, and **185"** shown in FIG. **3** allow many more groups to be selected on the basis of phase information. A possibly different group responds in the I and Q channels of the receiver of each antenna, and the groups may be different depending on which antenna or combination of antennas sends the carrier signal to the tags. Such group selection markedly cuts down the time needed to interrogate many tags in the field.

Base station antennas and tag antennas sensitive to circular and other polarizations are also known in the art, and these also may be used by one skilled in the art in an analogous way to that shown in FIGS. **1**, **2**, and **3** and described above.

An additional preferred embodiment of the invention is to use the information on the I and Q channels to select tags into groups on the basis of the phase of the returned signal which is dependent on the distance of the tags from the base station. As a tag is moved away from the base station, the carrier signal from the tag received at the base station changes from being in phase with the transmitted signal to being 90 degrees out of phase to being 180 degrees out of phase as the tag is moved one quarter of a wavelength of the RF EM field. The amplitude in the I channel and the Q channel changes accordingly, for example from a 1 in the I channel and a 0 in the Q channel, to a 0 in the I channel and a 1 in the Q channel, to a −1 in the I channel and 0 in the Q channel respectively. Thus, selecting the signals received from the tags on the I channel alone selects a group of tags for communication, while selecting the signals received from the tags on the Q channel selects a different group of tags which are at different distances from the base station antenna. Both the I and the Q channels may be used simultaneously or sequentially to communicate with the two different groups of tags. It is possible that some tags may be in both groups at the same time. As long as there are some tags in one group and not in the other, the selecting of the groups speeds up the tag communication protocol.

FIG. **7** gives a flow chart of a preferred method **700** of selecting groups of tags by the phase of the signal returned to the base station. A signal **710** is sent from the base station to the tags instructing the tags to return modulated signals to the base station in the time slot designated for tag response. In this time period, a steady carrier wave having a defined phase is transmitted **720** from the base station antenna. If a single tag can be read on the receiver I channel **730**, the tag is instructed to shut itself off in step **740** and the system returns to step **710**. If a single tag can not be read on the I channel in step **730**, the system tries to read a single tag in the Q channel in step **750**. If a single tag can be read step **750**, the tag is instructed to shut itself off in step **740**, and the system returns to the beginning **710** to try to pick up a single tag in the I channel. If single tags can not be read in either the I channel or the Q channel, the system decides in step **750** to institute the multiple tag in field reading procedure **760**. If tags are identified in either I or Q channels in step **760**, the system may shut the identified tags off and return to step **710** to try to find single tags grouped in the other channel.

While the above method **700** has steps **730** and **750** proceeding sequentially, it is well within the scope of the invention that steps **730** and **750** may also be carried out simultaneously. If a single tag is read on either the I channel or the Q channel, the system returns to step **710**. If no single tags are read on steps **730** and **750**, the system proceeds to step **760**. In step **760**, if tags are identified and shut off, the system may at any time return to step **710** to carry out the simpler subgrouping.

With the addition of an optional phase shifting element **139**, signals from a particular tag are brought entirely into the I channel or the Q channel. The tags may then be sorted into many more groups than the two groups defined by the I and Q channels as explained above. If only one channel of information, for example the I channel, is used, changing the phase shifting element **139** to give a series of different phase delays may sort the tags into more groups. The computer section **50** may end the phase shift element **135** instructions over line **157** to shift phase by, for example 0, 30, 60, and 90 degrees which would select four different groups of tags for communication. Using both the I and Q channels, and 3 phase shifts of 0, 30, and 60 degrees gives 6 groups as another example.

If the carrier signal frequency sent out from the base station is changed, a particular tag will be a different number of quarter wavelengths from the base station and the signal will be distributed in a different way between the I and Q channels of the base station receiver. A preferred embodiment of the present invention is to select different groups of tags according to the response of the tag to such a frequency shift of the base station. FIG. **8** gives a flow chart for the method **800** of selecting groups of tags on the basis of the response of the tag to the frequency of the carrier signal sent out from the base station. In step **810**, the base station sends out a carrier wave having a first frequency f_1. In step **820**, the base station instructs the tags to return signals. The signal returning to the base station is analyzed in a single channel of the receiver in step **830**. If the signal can be read, the tag is communicated with and turned off in step **840** and the system returns to step **820** to find single tags which may have less received signal strength than the tag found in the previous cycle. If no tag is found in step **830**, the system then changes the carrier frequency sent out from the base station in step **850** to a frequency f_2, and then sends signals to the tags to return signals in step **860**. If a single tag can be read in step **870**, the tag is communicated with and shut off in step **880**, and the system returned to step **860**. If no tags are found in step **870**, the system checks to see if any tags have been found in previous cycles through step **870**, and if so the system is returned to the beginning step **810** to search the first frequency again If no tags have been found in previous cycles, the system goes to the multiple tag in the field search procedure **890**. While two frequencies are used in this example, the method is not limited to the use of just two

frequencies, and many more could be used. Use of any plurality of frequencies which shift the relative phase of the returned signal is contemplated by the inventors.

A further embodiment of the invention is to select the tags into groups on the basis of the frequency response of the tags. Tags responsive to different carrier frequencies are interrogated, and the base station is programmed to shift from one frequency to the next to select and interrogate these different groups of tags in a sequential fashion. Tags may be grouped into tags which respond to 900 MHZ, and tags which respond to 2.4 MHZ, as an example.

A further embodiment of the invention is to select the tags into groups on the basis of the response of the tags to the RF power transmitted from the base station. The method of the embodiment is to send a low power to the set of tags, and communicate with the set of tags which respond to the low power, then turn the tags which responded to the low power off. Next, the RF power transmitted from the base station is raised, and tags in a group which are further away than the first group respond, and are in turn communicated with and turned off. The process may be repeated until all tags in communication range of the base station with the maximum power allowed have finished the communication protocol.

Tags which themselves return different carrier frequencies than the base station carrier frequency are known in the art. A further embodiment of the invention is to select groups of such tags on the basis of the different measured carrier frequencies. The base station is programmed to receive the different tag carrier frequencies, either simultaneously or sequentially and to interrogate each group of tags. The different carrier frequencies known in the art are often the harmonics of the base station carrier frequency. However, the invention is not limited to the particular carrier frequency returned by the tags to the base station. If the tags can be selected into at least two groups, the communication protocol is speeded up.

FIG. **9** is a flow chart of a method of grouping the tags on the basis of the carrier frequency of the tags. The receiver is set to receive a carrier signal of frequency f_1 in step **910**. Step **920** instructs the tags to return signals. If a single tag is read in step **930**, the system instructs the tag in step **940** to turn off and return to step **920**. If no tag can be read in step **930**, the receiver frequency is changed in step **950** to f_2, and the tags are instructed in step **960** to return signals. If a single tag can be read in step **970**, the tag is communicated with and shut off in step **980**. If a single tag can not be read in step **970**, the multiple tag reading protocol is instituted. While two frequencies are used in this example, many more frequencies could also be used.

The carrier frequencies emitted by the tags and received by the base station may be apparently shifted from the base station carrier frequency by the Doppler shift due to the relative motion of the tags and the base station A further embodiment of the invention is to select groups of tags according to the Doppler shift of the carrier frequency sent by the tags and received by the base station. As an example, two groups of tags, those with relative motion of the tags towards the base station, and those with relative motion away from the base station, are selected for the communication protocol. This group selection is particularly valuable for a base station communicating with tags on one side of a doorway, for example, to measure whether the tags are carried into or out of a room.

Tags may return different modulation frequencies. A further embodiment of the invention is to select groups of tags on the basis of the modulation frequency of the returned tag signal. The base station is programmed to interrogate each group of tags either simultaneously or sequentially.

The invention is not limited to the above examples. The selection of groups of tags from a set of tags on the basis of any physically measured characteristics or attributes of the returned signal from the tags in response to any physical characteristic or attribute of the signal sent from the base station is well within the scope of the invention, as is the combination of the selection of groups on the basis of both physically measured characteristics and information contained on the tags.

We claim:

1. A method for communicating between a base station and a set of radio frequency RF transponders (Tags) comprising:

defining a plurality of RF tags into different groups according to a physical wave characteristic of the electromagnetic wave energy received from the RF tags, and

communicating with the tags in each defined group.

2. A method as in claim **1** wherein at least one defining wave characteristic is the wave amplitude.

3. The method of claim **1** wherein at least one defining physical wave characteristic is the wave frequency.

4. The method of claim **1** wherein at least one defining physical wave characteristic is the polarization of the signal.

5. The method of claim **1** wherein at least one defining physical wave characteristic is the phase shift of a return signal.

6. The method of claim **1** wherein at least one defining physical wave characteristic is the strength of tie signal.

7. The method of claim **1** wherein at least one defining physical wave characteristic is the amplitude modulation of the signal.

8. The method of claim **1** wherein at least one defining physical wave characteristic is the wavelength of the signal.

9. An RF tag base station comprising

a computer

a transmitter

a receiver, and

at least one antenna,

wherein the RF tag base station communicates with a plurality of RF tags by:

interrogating the RF tags with electromagnetic energy,

grouping the RF tags according to a physical characteristic of their responsive electromagnetic signals, and

reading the RF tags in each group.

10. A base station as in claim **9** wherein RF tags are grouped according to the wave amplitudes of their respective return signals.

11. A base station as in claim **9** wherein RF tags are grouped according to the wave frequency of their respective return signals.

12. A base station as in claim **9** wherein RF tags are grouped according to the polarization of their respective return signals.

13. A base station as in claim **9** wherein RF tags are grouped according to the phase shift of their respective return signals.

14. A base station as in claim **9** wherein RF tags are grouped according to the strength of their respective return signals.

15. A base station as in claim **9** wherein RF tags are grouped according to the amplitude modulation of their respective return signals.

16. A base station as in claim 9 wherein RF tags are grouped according to the frequency modulation of their respective return signals.

17. A base station as in claim 9 wherein RF tags are grouped according to the wavelength of their respective return signals.

18. An RF tag unit reading unit comprising:

a computer;

a transmitter;

a receiver; and

at least one antenna;

wherein the RF tag reading unit communicates with a plurality of RF tags by:

interrogating the RF tags with electromagnetic energy;

grouping the RF tags according to a physical characteristic of their responsive electromagnetic signals, and

reading the RF tags in each group.

* * * * *

EXHIBIT G

US006400274B1

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(54) **HIGH-PERFORMANCE MOBILE POWER ANTENNAS**

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Related U.S. Application Data

(63) Continuation of application No. 09/321,986, filed on May 28, 1999, application No. 09/426,235, which is a continuation-in-part of application No. 09/277,768, filed on Jan. 8, 1999, now Pat. No. 6,243,013, said application No. 09/321,986, is a continuation-in-part of application No. 08/733,684, filed on Oct. 17, 1996, now Pat. No. 5,889,489, which is a continuation-in-part of application No. 08/521,898, filed on Aug. 31, 1995, now Pat. No. 5,606,323, application No. 09/426,235, and a continuation-in-part of application No. 09/211,584, filed on Dec. 14, 1998, and a continuation-in-part of application No. 09/195,733, filed on Nov. 19, 1998, which is a continuation-in-part of application No. 09/114,037, filed on Jul. 10, 1998, which is a continuation of application No. 08/626,820, filed on Apr. 3, 1996, now Pat. No. 5,850,181, said application No. 09/321,986, and a continuation-in-part of application No. 09/266,973, filed on Mar. 12, 1999, which is a continuation-in-part of application No. 09/263,057, filed on Mar. 6, 1999, now abandoned.

(60) Provisional application No. 60/086,972, filed on May 28, 1998, provisional application No. 60/077,094, filed on Mar. 6, 1998, provisional application No. 60/077,872, filed on Mar. 13, 1998, and provisional application No. 60/070,347, filed on Jan. 2, 1998.

(51) **Int. Cl.**[7] **G08B 13/14**

(52) **U.S. Cl.** **340/572.7**; 340/572.1; 342/44

(58) **Field of Search** 340/572.7, 572.6, 340/572.4, 10.1, 10.34, 539, 551; 342/27, 44, 51

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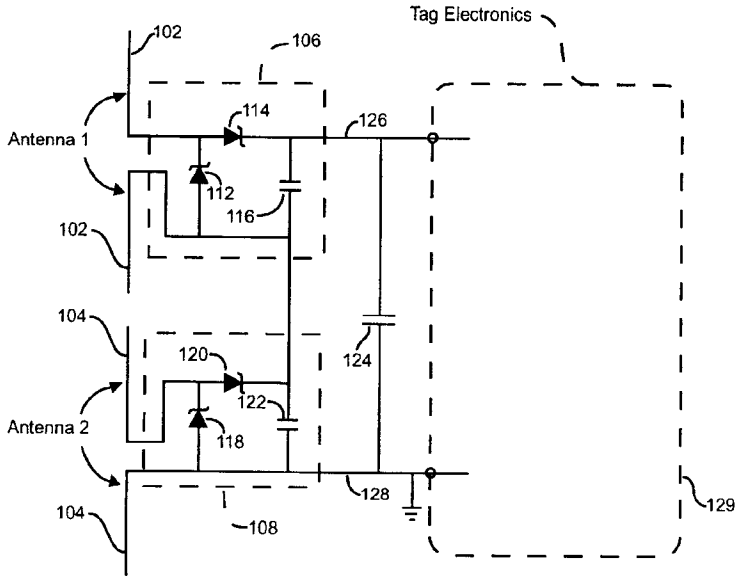
Primary Examiner—John A Tweel
(74) *Attorney, Agent, or Firm*—Rodney T. Hodgson

(57) **ABSTRACT**

An RFID tag's mobility can be increased and cost can be decreased by using high-performance mobile power antennas instead of battery powered tags. Disclosed are some power antennas that include a half wave rectifier, a full wave rectifier, and a voltage multiplier. These antennas can be cascaded to boost the power or voltage gain. Additionally, planar elements can be added to increase efficiency without decreasing mobility.

34 Claims, 7 Drawing Sheets



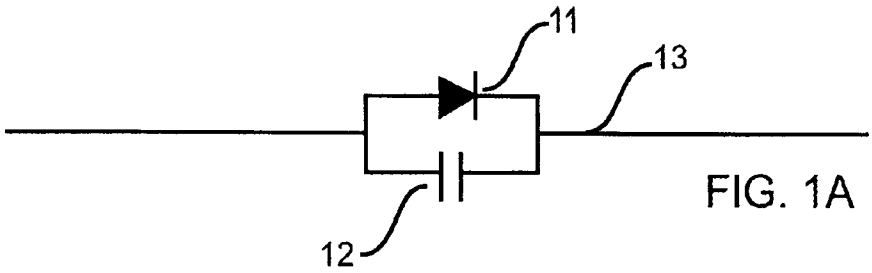


FIG. 1A

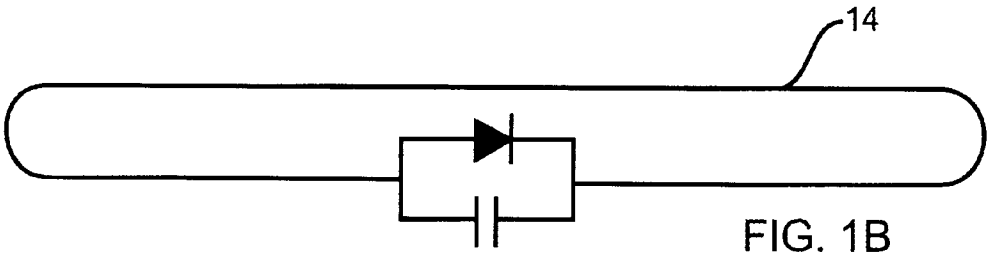


FIG. 1B

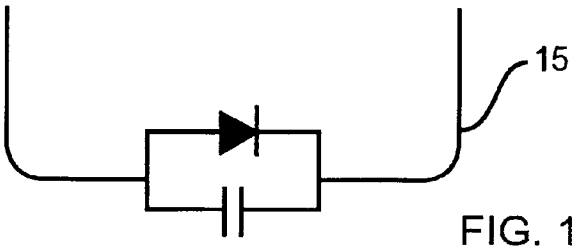


FIG. 1C

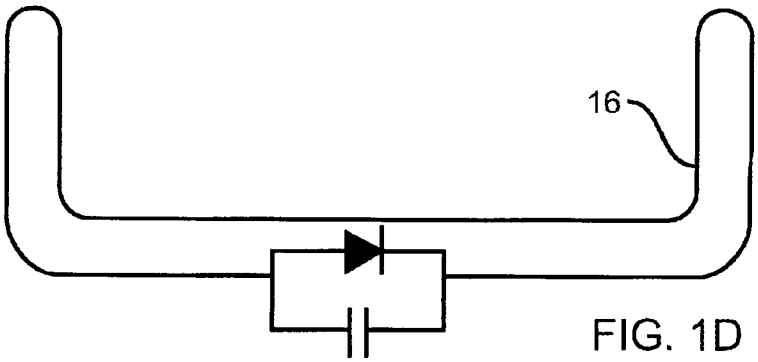


FIG. 1D

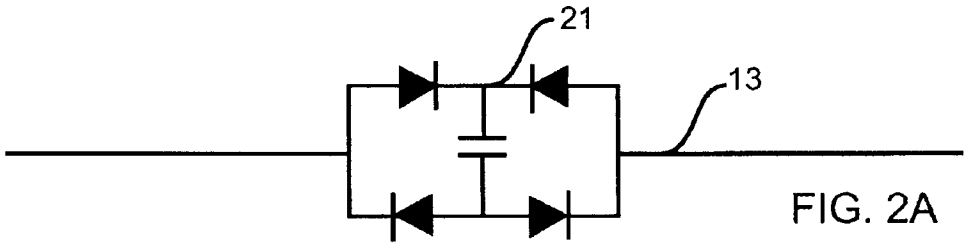


FIG. 2A

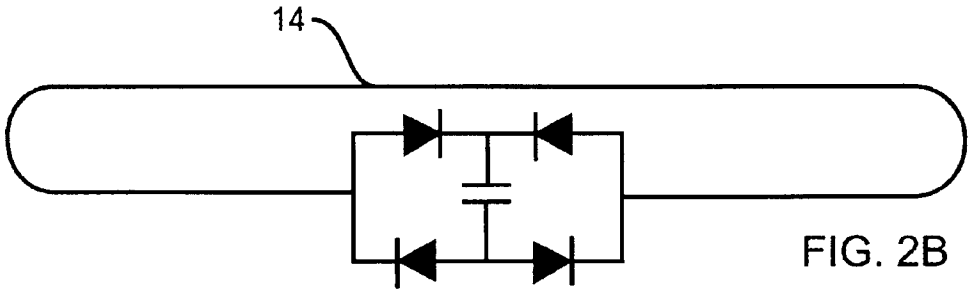


FIG. 2B

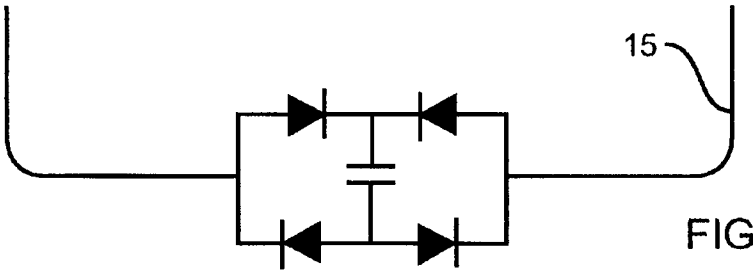


FIG. 2C

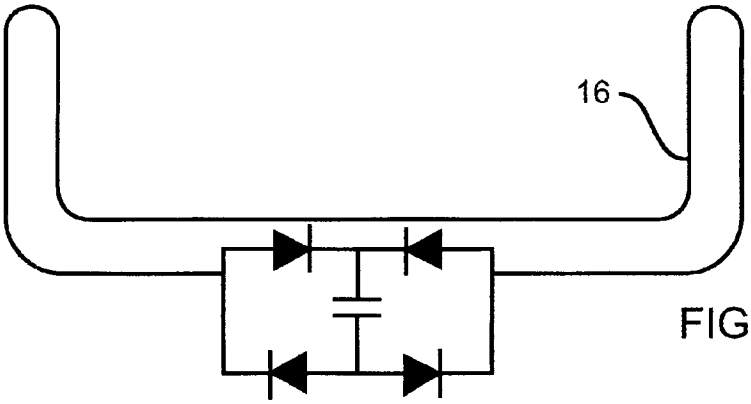


FIG. 2D

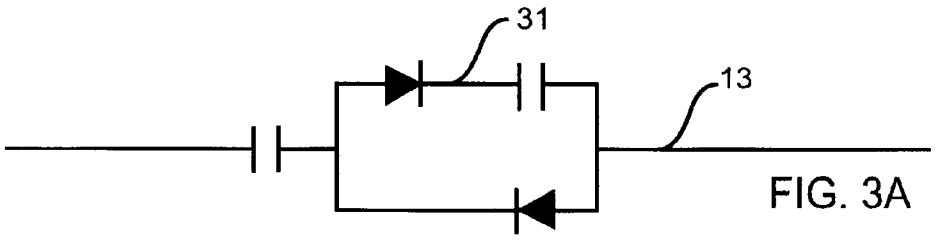


FIG. 3A

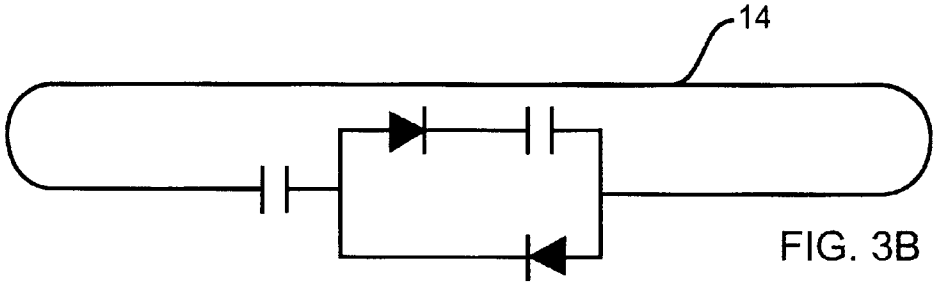


FIG. 3B

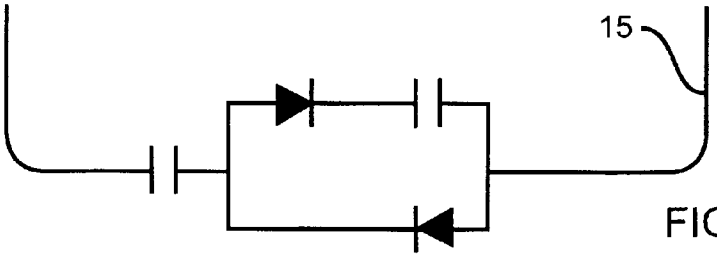


FIG. 3C

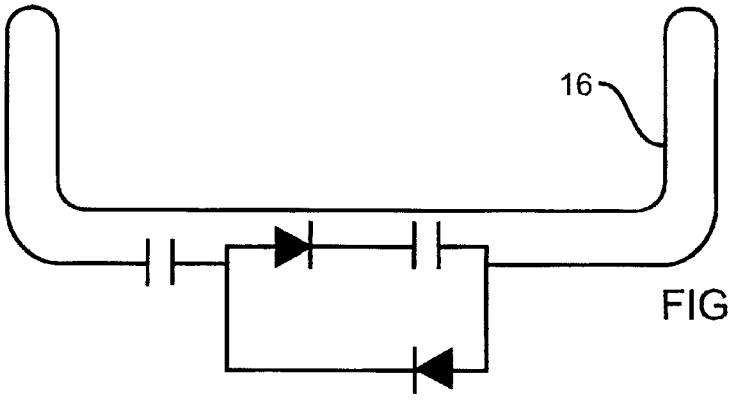


FIG. 3D

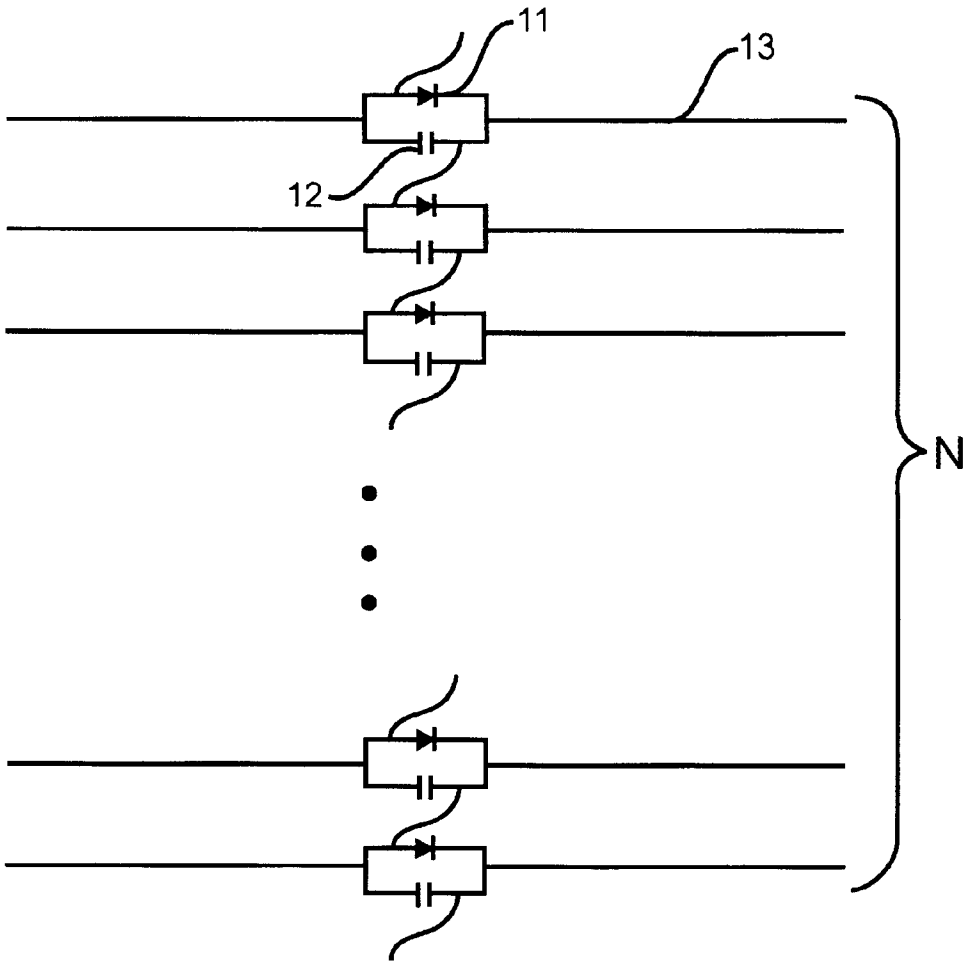


FIG. 4

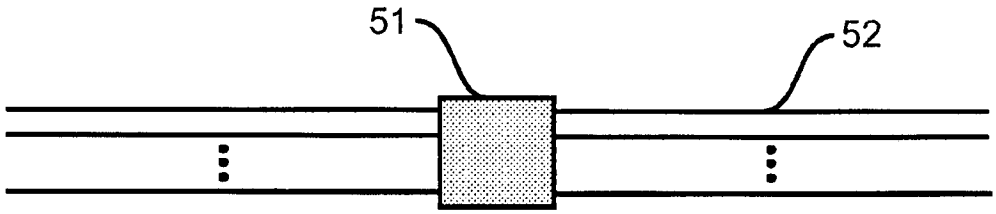


FIG. 5A

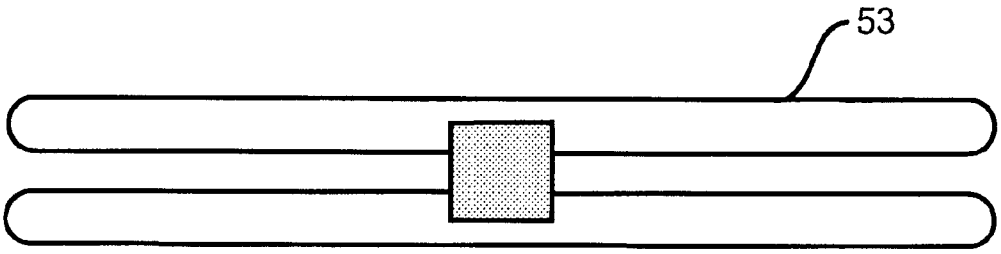


FIG. 5B

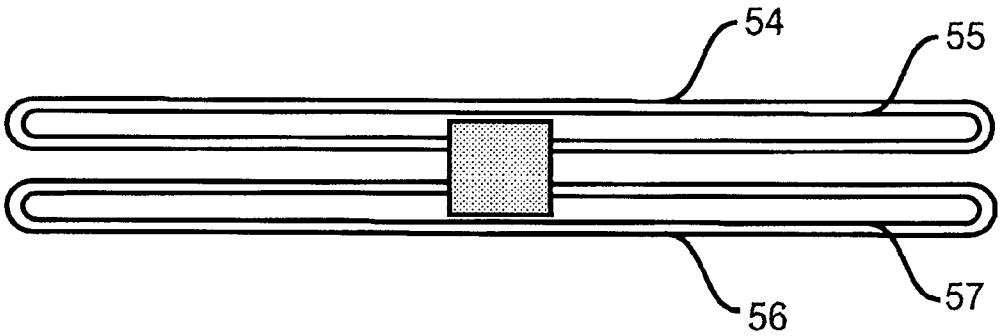


FIG. 5C

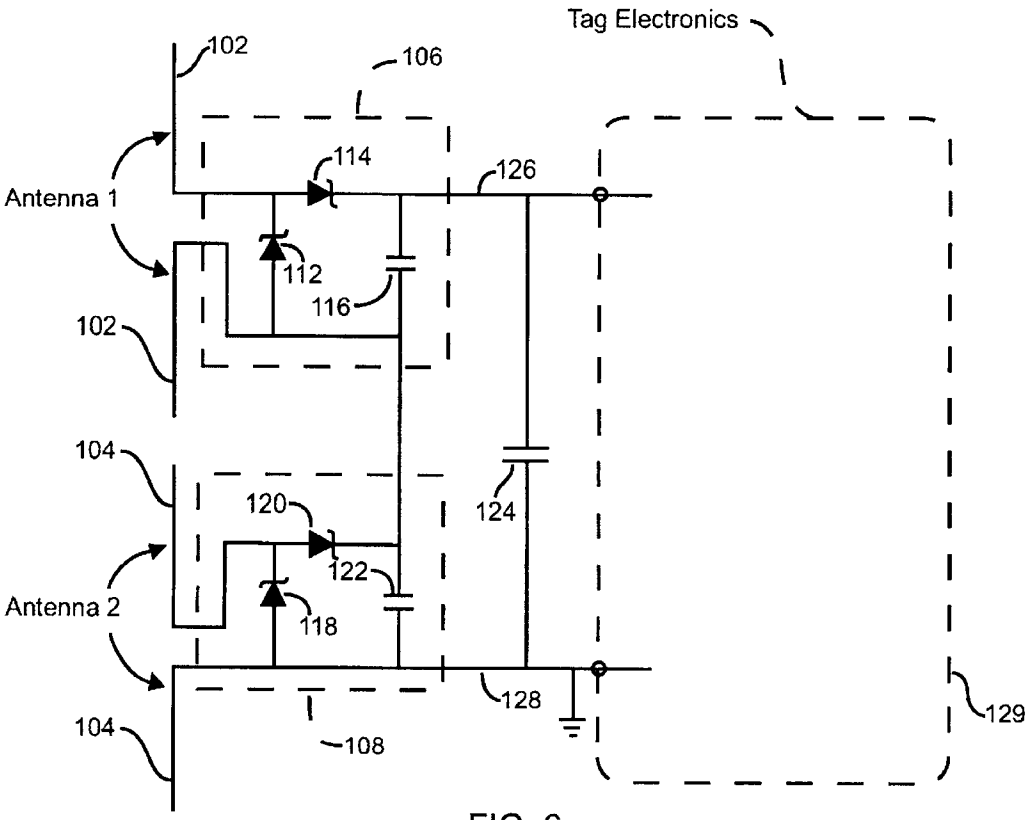

Tag Electronics
102
106
114
126
Antenna 1
112
116
102
104
120
124
122
Antenna 2
118
128
129
104
108

FIG. 6

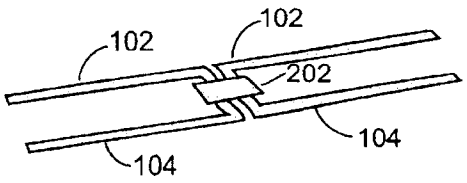


FIG. 7

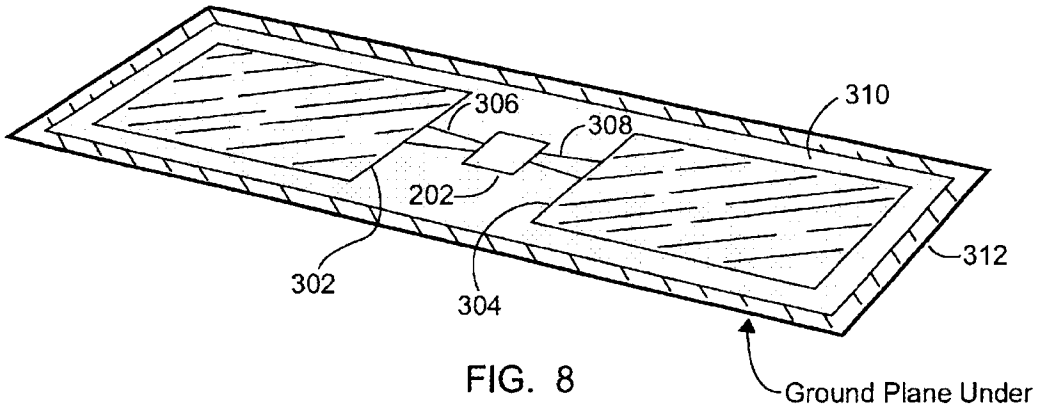


FIG. 8

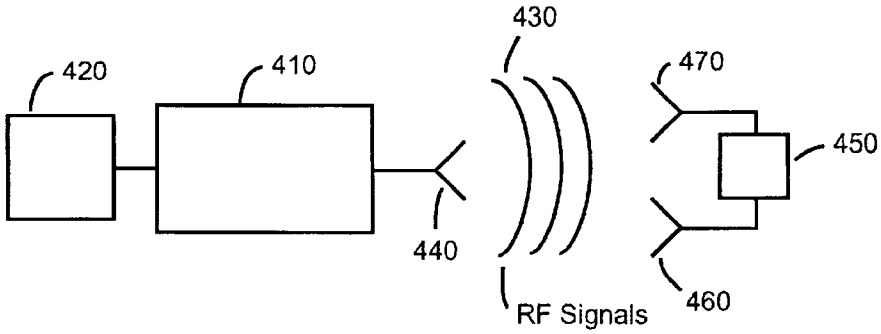


FIG. 9

HIGH-PERFORMANCE MOBILE POWER ANTENNAS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of application Ser. No. 09/321,986 filed May 28, 1999, which claims the benefit of provisional application No. 60/086,972 filed May 28, 1998, which application is specifically incorporated herein, in its entirety, by reference. The present application is a continuation-in-part of copending application Ser. No. 09/227,768 filed Jan. 8, 1999. Said application Ser. No. 09/321,986 is a continuation-in-part of application Ser. No. 08/733,684 filed Oct. 17, 1996, now U.S. Pat. No. 5,889,489 issued Mar. 30, 1999, which in turn is a continuation-in-part of application Ser. No. 08/521,898 filed Aug. 31, 1995, now U.S. Pat. No. 5,606,323 issued Feb. 25, 1997. The present application is a continuation-in-part of copending applications Ser. No. 09/114,037 filed Jul. 10, 1998, Ser. No. 09/195,733 filed Nov. 19, 1998, and Ser. No. 09/211,584 filed Dec. 14, 1998, which is a continuation of Ser. No. 08/626,820 filed Apr. 3, 1996, now U.S. Pat. No. 5,850,181 issued Dec. 15, 1998. Said application Ser. No. 09/321,986 is also a continuation in-part of application Ser. No. 09/263,057 filed Mar. 6, 1999 which claims the benefit of provisional application No. 60/077,094 filed Mar. 6, 1998, and a continuation in-part of application No. Ser. 09/266,973 filed Mar. 12, 1999 which claims the benefit of provisional application No. 60/077,872 filed Mar. 13, 1998. application Ser. No. 09/222,598 filed Dec. 29, 1998, provisional application No. 60/070,347 filed Jan. 2, 1998, and U.S. Pat. No. 5,606,323 issued Feb. 25, 1997 are each incorporated herein by reference in its entirety. All of the above provisional and nonprovisional applications are hereby incorporated herein by reference in their entireties including drawings and appendices.

FIELD OF THE INVENTION

The field of the invention relates to the field of Radio Frequency (RF) transponders (RF Tags) which receive RF electromagnetic radiation from a base station whether or not the RF tags have a battery (which may be charged by the received RF energy), and send information to the base station by modulating the load of an RE antenna,

BACKGROUND OF THE INVENTION

There are many wireless communication applications in the prior art that use mobile communication units. One application area is radio frequency identification (RF ID) systems, which involve a large number of these mobile units. A mobile antenna is an antenna that is attached to an article capable of moving.

There is a desire to minimize the cost of these mobile units, particularly when, such as in RF ID, there are a large number of mobile units in a system. While a battery is a reliable way to supply power to these mobile units, there are significant manufacturing costs incurred in using this device. Furthermore, batteries dictate certain shapes of the mobile unit, occupy area on the mobile circuit, and reduce the mechanical flexibility of the mobile circuit.

Passive mobile circuits exist in the prior art that have no battery supplying power to the circuit. These passive mobile circuits use the antenna structure on the circuit to seize energy from an electromagnetic field received by the passive circuit. The antenna used the energy in the field to provide

the passive circuit with the power (both energy and voltage) to operate. In addition, these antennas detect (field detection) the presence of the electromagnetic field and may re-radiate a signal.

Typical field probing antennas in the prior art are made of short (non-resonant) dipoles loaded with a diode that is connected to the signal processing equipment (part of the mobile circuit) via a pair of high-impedance leads. These field-probing antennas are designed to minimize the disturbance to the field being detected.

One fundamental problem with passive tags is that the range is limited by the voltage picked up by the tag antenna and rectified by the tag power conditioning circuits. The voltage must be high enough to run the tag electronics, and the voltage is generally the limiting factor in determining the distance from the base station antenna at which the tags may be used. Even active tags having a battery to run the tag electronics are limited in the voltage picked up by the tag antenna.

SUMMARY

Included are several variations of a mobile power antenna. Disclosed are resonant antennas coupled to a half wave rectifier, a full wave rectifier, and a voltage multiplier. This disclosure also shows a cascaded antenna. Additionally, planar elements can be added to these antennas to increase efficiency without reducing mobility.

The present invention also relates to a system, apparatus and method to use multiple antennas to receive RF power and signals from a base station, where circuitry is provided which will cascade the DC voltages produced by rectifying the signals at each of the multiple antennas.

An object of this invention is an improved antenna for powering a passive circuit on a mobile unit. A second object of this invention is an improved antenna for powering a passive circuit on a mobile unit when the antenna is non-resonant with the received frequency. A third object of this invention is an improved antenna for collecting power from an electromagnetic field of minimal power. A fourth object of this invention is an improved antenna and associated circuit for generation of a voltage from an electromagnetic field of minimal power.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A–1D** show antennas that utilize a half wave rectifying structure.

FIGS. **2A–2D** show antennas that utilize a full wave rectifying structure.

FIGS. **3A–3D** show antennas that utilize a voltage doubling structure.

FIG. **4** show cascaded antennas.

FIGS. **5A–5C** show antennas with planar elements.

FIG. **6** shows a sketch of a circuit diagram for receiving power from two tag antennas.

FIG. **7** shows a sketch of an RF tag having two dipole antennas.

FIG. **8** shows a sketch of an RF tag having two patch antennas.

FIG. **9** shows a sketch of a system for communicating power and information between a base station and an RF tag.

DETAILED DESCRIPTION

Several mobile power antennas with resonant structures are designed and depicted in FIGS. **1A–1D**. FIG. **1A** shows

a half wave dipole (13) loaded with a diode (11) and a capacitor (12). FIG. 1B illustrates a fill-wave folded-dipole antenna (14), which may double or quadruple the rectified voltage across the diode depending on the intensity of the incident wave. FIG. 1C demonstrates a resonant bent-dipole antenna (15), in which reduced polarization sensitivity and broadened bandwidth is realized. FIG. 1D is a folded-dipole antenna (16) bent for similar purpose. It must be emphasized that the antennas in FIGS. 1A–1D can all be implemented in a planar structure, and possess a minimum area for the functionality described. These characteristics facilitate low-cost manufacturing process.

Antennas in FIGS. 1A–1D utilize only the half cycle (of the incident field) in which the diode is conducting to establish a voltage. In order to improve the efficiency in collecting power, one may apply a full-wave rectifying circuit (FIGS. 2A–2D, part labeled 21), across the antenna terminals to extract energy from the field in both half cycles. When a larger voltage needs to be established, on the other hand, one may use a voltage-multiplying circuit that produce N times the voltage for the same incident field intensity. FIGS. 3A–3D depict an example: antennas with a voltage-doubling circuit (31). The combination of resonant structures and appropriate rectifying circuits result in antennas with high-performance powering capabilities. It should be mentioned that the increased number of devices in FIGS. 2A–2D or FIGS. 3A–3D do not increase the manufacturing cost if they are built as part of an integrated circuit.

One may use a cascaded antenna array to achieve ultra-high rectified voltages as shown in FIG. 4, in which the element antennas, being illustrated by dipoles, can be any of those depicted in FIGS. 1A–1D, 2A–2D, or 3A–3D. The rectified voltage is increased N times for N antennas in tandem. For all antennas mentioned above, a pair of not-high-impedance leads is used to extract the power to the load (circuitry). The range of optimum impedance for each configuration depends on the antenna impedance, can be determined experimentally using a pair of leads with variable resistance.

Three-dimensional constructions such as via holes, jumping wires, etc, are costly to manufacture. It is therefore desirable to conceive two-dimensional (planar) layouts for the cascaded antenna arrays. Several of these planar implementations are illustrated in FIGS. 5A, 5B and 5C, in which the gray-shaded boxes (51) represent IC's that contain the necessary rectifying circuits and other processing circuitry. FIG. 5A shows how to attach an array of several dipoles (52) to an IC in planar fashion. Obviously, a limiting factor on the maximum number of dipoles is the circumference of the IC. FIG. 5B illustrates a planar two-element folded-dipole antenna array (53). Although not depicted, the bent antennas can also be arrayed in a way similar to FIGS. 5A or 5B depending on whether the antennas have open ends or closed ends. A mixture of open-ended and close-ended antennas may be combined in the same array. If more than two folded-dipole antennas are to be arranged two-dimensionally, one may have to use different but similar antenna sizes (54–57) as shown in FIG. 5C. Besides improved powering capability, this "embedded" topology is preferred for broadened bandwidth.

U.S. Pat. No. 5,850,181 issued Dec. 15, 1998 illustrates overall systems for supplying RF energy to passive radio frequency identification transponders, which systems are specifically applied to passive RFID tags incorporating each of the respective configurations of antennas 13–16, 52, 53 and 54–57, with each of the power collection circuits 11, 21, 31 and 51 (and including each of the antenna-circuit configurations specifically shown in FIGS. 1A–1D, 2A–2D, 3A–3D, 4 and 5A–5C. Where such RF tags are to be energized by RF signals of different frequencies in a given frequency band such as 902–928 MHz, 2400–2483.5 MHz and 5725–5850 MHz, the antenna-power collection circuit configurations disclosed herein may be resonant at a mean or median frequency of the respective frequency band, so that the antenna-power collection circuit configurations are substantially resonant at the respective frequencies of the given frequency band, and power is extracted to the load circuitry from the antenna-power collection circuit configurations by a pair of not-high-impedance leads which present an impedance selected experimentally for maximum power transfer to the load circuitry, for example.

An information signal may be derived from the antenna configurations disclosed herein, as shown in the various embodiments of Friedman and Heinrich patent application Ser. No. 08/733,684 filed Oct. 17, 1996, which is hereby incorporated herein by reference in its entirety. U.S. Pat. No. 5,606,323 issued Feb. 25, 1997 is also incorporated herein by reference in its entirety for disclosing passive RF tags to which the teachings of the present invention may be applied.

FIG. 6 shows a sketch of a circuit diagram for receiving power from two tag antennas 102 and 104. Tag antennas 102 and 104 are sketched here as dipole antennas, but they could be any one or any combination of dipole, patch, loop, or slot antennas as are known in the art. Tag antennas 102 and 104 could also be any one of the above and/or any one or any combination of DOG, HOG, or SOG antennas which are described in great detail in: U.S. application Ser. No. 09/191,641 filed Nov. 13, 1998 by Duan et al. entitled "RF Identification Transponder having a spiral antenna", now U.S. Pat. No. 6,118,379 issued Sep. 12, 2000; U.S. application Ser. No. 09/192,063 filed Nov. 13, 1998 by Duan et al. entitled "RF Identification Transponder having a helical antenna"; U.S. application Ser. No. 09/191,642 filed Nov. 13, 1998 by Duan et al. entitled "RF Identification Transponder employing patch antenna", now U.S. Pat. No. 6,215,402 issued Apr. 10, 2001; and U.S. application Ser. No. 09/192,052 filed Nov. 13, 1998 by Duan et al. entitled "Distributed Impedance matching circuit for high reflection coefficient load", now U.S. Pat. No. 6,177,872 issued Jan. 23, 2001, which are hereby incorporated by reference in this application. Of particular importance to the invention are the innovative impedance matching schemes noted in the above identified applications. Tag antennas 102 and 104 are shown in FIG. 6 providing power and information to voltage doubling circuits 106 and 108 respectively. Voltage doubling circuits 106 and 108 are well known voltage doubling circuits for providing power to passive RF tags, and could be replaced with single rectification circuits or higher order cascade voltage multiplication circuits as known in the art. RF diodes 112 and 114 act together to charge capacitor 116. Elements 118, 120 and 122 perform a similar function in circuit 108. Circuits 106 and 108 charge capacitor 124 to a voltage twice the voltage available with a single RF diode; capacitor 124 may act as a power supply for tag electronics 129, or may act as a modulated signal receiver for tag electronics in the case that the tag electronics 129 have a battery power supply as in the case of an active RF Tag. Power or signals are fed into the tag electronic section over lines 126 and 128 respectively. Line 128 is shown as the conventional ground. The tag electronics may also receive modulated signals by many other means than by measuring voltage across capacitor 124. For example, signals may be recovered by measuring the voltage across capacitors 116 or 122, or receiving circuits may be added as shown in incor-

porated U.S. Pat. application Ser. No. 08/733,684, (now U.S. Pat. No. 5,889,489 issued Mar. 30, 1999) which are completely apart from the power receiving circuis **106** and **108**.

The tag electronics may also receive modulated signals by many other means than by measuring voltage across capacitor **124**. For example, signals may be recovered by measuring the voltage across capacitors **116** or **122**, or receiving circuits may be added as shown in incorporated U.S. Pat. application Ser. No. 08/733,684 which are completely apart from the power receiving circuits **106** and **108**.

Modulation of the antenna reflectance characteristics to send signals from the tag to the base station may be performed by modifying the bias conditions on one or more ofdiodes **112**, **114**, **118**, **120**, or by shorting out capacitors **116**, **122**, and/or **124** under control of the tag electronic circuitry. (Circuits not shown).

FIG. **7** shows a sketch of an RF tag having two dipole antennas **102** and **104** connected to a semiconductor chip **202** which contains the tag electronic circuitry and the RF diodes and capacitors shown in FIG. **6**. The dipole antennas **102** and **104** may be close together and closely coupled as shown in FIG. **7**, or they may be widely separated (by more than the wavelength of the RF radiation which they are receiving) and hence not closely coupled.

FIG. **8** shows a sketch of an RF tag having two patch antennas **302** and **304** feeding power or information to a semiconductor chip **202** through impedance matching sections **306** and **308**. Impedance matching strips **306** and **308** may be short so that patch antennas **302** and **304** are closely coupled, or may be long so that they are not closely coupled. Patch antennas **302** and **304** are made from electrically conducting material such as metal or conducting polymer material, and are generally connected to a dielectric material **310** which separated patches **302** and **304** from a conducting ground plane **312**.

From FIGS. **7** and **8**, it is easy to see that one patch antenna may be combined with one dipole antenna to produce more voltage than a single antenna. Note also that patch antennas **302** and **304** could both be circular polarized antennas of opposite handedness, so that at least some voltage would be generated by the combination, where a single antenna might not receive any power or information. In the same way, dipole antennas **102** and **104** could be constructed so that they are mutually perpendicular, instead of parallel as shown. In this case, linearly polarized RF radiation would give at least some power to the combination of the two antennas.

FIG. **9** shows a sketch of a base station **410** connected to a computer **420** which is used to send and receive RF signals **430** through antenna **440** to and from an RF tag **450** having two antennas **460** and **470**. Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise then as specifically described.

RELATED PATENTS AND APPLICATIONS

Related U.S. patents assigned to the assignee of the present invention include: U.S. Pat. Nos. 5,521,601; 5,528,222; 5,538,803; 5,550,547; 5,552,778; 5,554,974; 5,563,583; 5,565,847; 5,606,323; 5,635,693; 5,673,037; 5,680,106; 5,682,143; 5,729,201; 5,729,697; 5,736,929; 5,739,754; 5,767,789; 5,777,561; 5,786,626; 5,812,065; 5,821,859; 5,850,181; and 5,874,902. U.S. patent applications assigned to the assignee of the present invention include: application Ser. No. 08/694,606 filed Aug. 9, 1996 entitled "RFID System with Write Broadcast Capability" by Cesar et al.; (now U.S. Pat. No. 5,942,987 issued Aug. 24, 1999); application Ser. No. 08/790,639 filed Jan. 29, 1997, (now U.S. Pat. No. 6,097,347 issued Aug. 1, 2000) ; application Ser. No. 08/790,640 filed Jan. 29, 1997, now U.S. Pat. No. 6,028,564 issued Feb. 22, 2000); application Ser. No. 09/153,617 filed Sep. 15, 1998, entitled "RFID Interrogator Signal Processing System for Reading Moving Transponder," by Zai et al., (now U.S. Pat. No. 6,122,329 issued Sep. 19, 2000); application Ser. No. 08/862,149 filed May 23, 1997; application Ser. No.08/862,912 filed May 23, 1997, (now U.S. Pat. No. 5,966,082 issued Oct. 12, 1999); application Ser. No. 08/862,913 filed May 23, 1997 (now U.S. Pat. No. 6,288,629 issued Sep. 11, 2001); application Ser. No. 60/079,852 filed Mar. 30, 1998; application Ser. No. 09/277,271 filed Mar. 26, 1999, (now U.S. Pat. No. 6,147,606 issued Nov. 14, 2000); application Ser. No. 60/079/391 filed Mar. 26, 1998; and U.S. application Ser. No. 09/192,052 filed Nov. 13, 1998 by Duan et al. entitled "Distributed Inpedance Matching Circuit for High Reflection Coefficient Load", (now U.S. Pat. No. 6,177,872 issued Jan. 23, 2001). The above identified U.S. patents and U.S. patent applications are hereby incorporated herein by reference in their entireties.

The following U.S. patent applications are hereby incorporated herein by reference in their entirety. Application Ser. No. 08/790,640, filed on Jan. 29, 1997 for Duan, et al., entitled "Wire Antenna with Stubs to Optimize Impedance for Connecting to a Circuit".

The following U.S. provisional patent applications are hereby incorporated herein by reference in their entirety. Application Ser. No. 60/079,613, filed on Mar. 27, 1998 for Duan, et al., entitled "Methods of Maximizing Operating Distance for RFID Tags". Application Ser. No. 60/078,287, filed on Mar. 17, 1998 for Duan, et al., entitled "Methods of Impedance Matching for Circularly-Polarized Patch Antenna RFID Tag". Application Ser. No. 60/078,220, filed on Mar. 16, 1998 for Duan, et al., entitled "RFID Tags Using High Gain Antennas".

In view of the above disclosure of the present application, including all associated drawings, and the material incorporated hereby by reference, other modifications, adaptations, variations and alternative embodiments may be effected without departing from the spirit and scope of the present disclosure.

INCORPORATION BY REFERENCE

Related U.S. patent application "Cascaded DC Voltages of Multiple Antenna RF Tag Front-end Circuits" with application Ser No. 09/227,768 filed on Jan. 8, 1999 is herein incorporated by reference.

What is claimed is:

1. An RF tag system for collecting power from an electromagnetic field with a carrier frequency comprising:

an antenna configuration that is substantially resonant at the carrier frequency and is excited by the electromagnetic field to cause an induced current to be present at antenna terminals of the antenna configuration, the induced current being at the carrier frequency;

one or more rectifiers that rectifies the induced current at the antenna terminals;

one or more capacitors that collects the rectified induced current to develop a voltage sufficient to power an electric circuit; and

attached RF tag circuitry comprising the electric circuit.

2. An antenna power collector system for collecting power from an electromagnetic field with a carrier frequency comprising:

a dipole antenna that is substantially resonant with the carrier frequency and is excited by the electromagnetic field that causes an induced current to be present at two antenna terminals, the induced current being at the carrier frequency;

one or more rectifiers that rectifies the induced current at the antenna terminals;

a modulation circuit that shorts and opens the antenna terminals at a modulation frequency in order to change the antenna impedance;

one or more capacitors that collect the rectified induced current to develop a voltage sufficient to power an electric circuit, the voltage being developed within one period of the modulation frequency.

3. An antenna power collector system, as in claim **2**, where the rectifier and capacitor form a half wave rectifier.

4. An antenna power collector system, as in claim **3**, where the dipole antenna is a folded dipole antenna.

5. An antenna power collector system, as in claim **3**, where the dipole antenna is a bent dipole antenna.

6. An antenna power collector system as in claim **3**, where the dipole antenna is a bent, folded dipole antenna.

7. An antenna power collector system, as in claim **2**, where the rectifier and capicitor form a full wave recifier.

8. An antenna power collector system as in claim **7**, where the dipole antenna is a folded dipole antenna.

9. An antenna power collector system, as in claim **7**, where the dipole antenna is a bent dipole antenna.

10. An antenna power collector system, as in claim **7**, where the dipole antenna is a bent, folded dipole antenna.

11. An antenna power collector system, as in claim **2**, where the recifier and capicitor form a voltage doubling circuit.

12. An antenna power collector system, as in claim **11**, where the dipole antenna is a folded dipole antenna.

13. An antenna power collector system, as in claim **11**, where the dipole antenna is a bent, folded dipole antenna.

14. An antenna power collector system, as in claim **11**, where the dipole antenna is a bent, folded dipole antenna.

15. An antenna power collector system, as in claim **2**, where the rectifier and capacitor form a voltage N multiplier circuit.

16. An antenna power collector system, as in claim **15**, where the dipole antenna is a folded dipole antenna.

17. An antenna power collector system, as in claim **15**, where the dipole antenna is a bent dipole antenna.

18. An antenna power collector system, as in claim **15**, where the dipole antenna is a bent, folded dipole antenna.

19. An antenna power collector system for collecting power from an electromagnetic field with a carrier frequency comprising:

a dipole antenna that is resonant with the carrier frequency and is excited by the electromagnetic field that causes an induced current to be present at two antenna terminals, the induced current being at the carrier frequency;

one or more rectifiers that rectifies the induced current at the antenna terminals;

a modulation circuit that shorts and opens the antenna terminals at a modulation frequency in order to change the antenna impedance;

one or more capacitors that collect the rectified induced current to develop a voltage sufficient to power an electric circuit, the voltage being developed within one period of the modulation frequency, the capacitors combined with the rectifiers to form two or more rectifier circuits that are connected in series to increase the voltage that powers the electric circuit.

20. An antenna power collector system, as in claim **19**, where the rectifier circuits can be any of the type including a half wave rectifier, a full wave rectifier, a voltage doubler, and a voltage multiplier.

21. An antenna power collector syste, as in claim **20**, where the dipole antenna is a folded dipole antenna.

22. An antenna power collector system, as in claim **20**, where the dipole antenna is a bent dipole antenna.

23. An antenna power collector system, as in claim **20**, where the dipole antenna is a bent, folded dipole antenna.

24. An antenna power collector system for collecting power from an electromagnetic field with a carrier frequency comprising: p1 an array of two or more dipole antennas that are resonant at the carrier frequency and are excited by the electromagnetic field to cause an induced current to be present at two antenna terminals on each of the antennas, the induced current being at the carrier frequency;

one or more rectifiers associated with each antenna that rectifies the induced current at the antenna terminals of each antenna respectively;

a modulation circuit that shorts and opens all the antenna terminals at a modulation frequency in order to change the antenna impedance of each antenna;

one more capacitors associated with each antenna that collects the rectified induced current and together with the rectifier associated with the respective antenna forms a rectifier circuit for each antenna; whereby the rectifier circuit for each antenna is connected in series to develop a voltage sufficient to power an electric circuit, the voltage being developed within one period of the modulation frequency.

25. An antenna power collecting system, as in claim **24**, where one or more of the rectifying circuits is a half wave rectifier.

26. An antenna power collecting system, as in claim **24**, where one or more of the rectifying circuits is a full wave rectifier.

27. An antenna power collecting system, as in claim **24**, where one or more of the rectifying circuits is a voltage doubler.

28. An antenna power collecting system, as in claim **24**, where one or more of the rectifying circuits is a voltage multiplier.

29. An antenna power collecting system, as in claim **24**, where one or more of the dipoles is coplanar with the connections connecting the rectifier circuits.

30. An antenna power collecting system, as in claim **29**, where one or more of the dipoles is a folded dipole antenna.

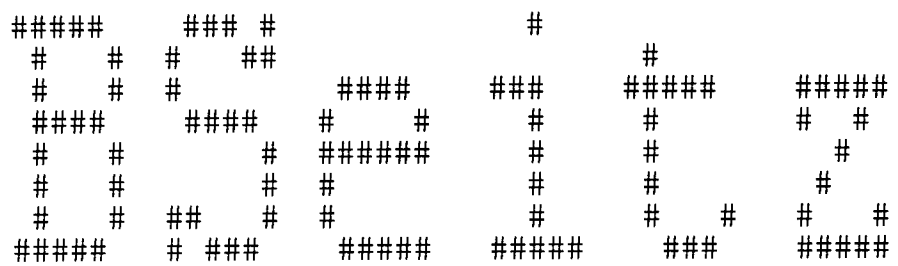
31. An antenna power collecting system, as in claim **29**, where one or more of the dipole antennas is a bent dipole antenna.

32. An antenna power collecting system, as in claim **29**, where one or more of the dipole antennas is a folded, bent dipole antenna.

33. An antenna power collecting system, as in claim **30**, where one or more of the folded dipole antnas surrounds one or more other folded dipole antennas.

34. An antenna power collecting system, as in claim **33**, where the folded dipole antennas are within twenty percent of each other in length.

* * * * *



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US005850181A

United States Patent [19]

Heinrich et al.

[11] Patent Number: 5,850,181

[45] Date of Patent: Dec. 15, 1998

[54] **METHOD OF TRANSPORTING RADIO FREQUENCY POWER TO ENERGIZE RADIO FREQUENCY IDENTIFICATION TRANSPONDERS**

[75] Inventors: **Harley Kent Heinrich**, Brewster; **Rene Dominic Martinez**, Putman Valley, both of N.Y.; **Paul Jorge Sousa**, Middleton, Mass.; **Li-Cheng Richard Zai**, Ossining, N.Y.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **626,820**

[22] Filed: **Apr. 3, 1996**

[51] **Int. Cl.**[6] **G08B 13/14**

[52] **U.S. Cl.** **340/572**; 340/693

[58] **Field of Search** 340/572, 825.54, 340/825.69, 693; 342/42, 44, 51; 375/202

[56] **References Cited**

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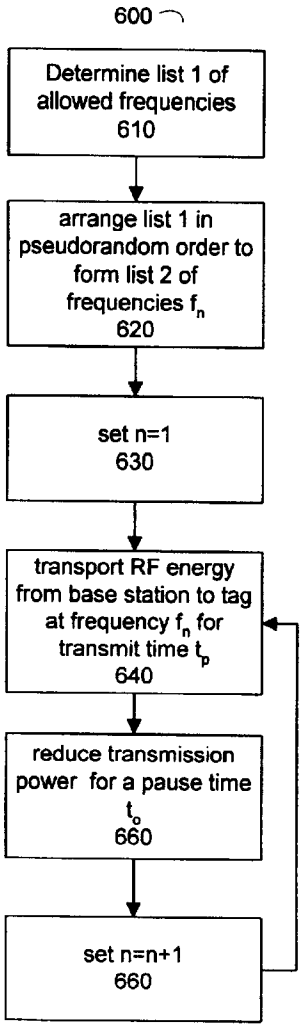
Primary Examiner—Thomas J. Mullen, Jr.
Attorney, Agent, or Firm—Rodney T. Hodgson

[57] **ABSTRACT**

An apparatus and a method of transporting energy from a base station to energize a remote RF transponder having an energy store is described, comprising transporting power in pulses of frequencies chosen from a randomly ordered list of frequencies, wherein the time between pulses when little power is transmitted is less than the time taken for the remote transponder to deplete the energy store.

30 Claims, 2 Drawing Sheets



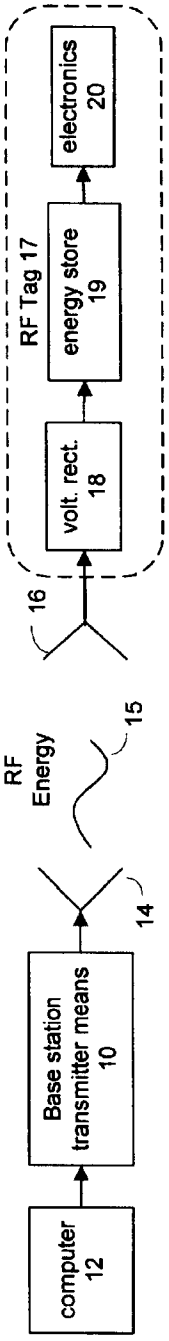


Fig. 1

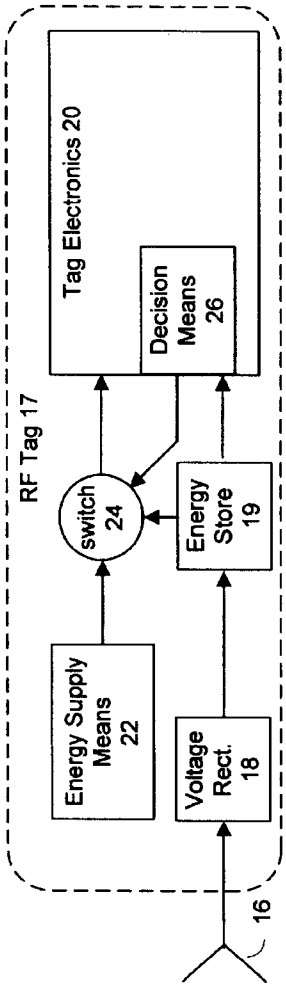


Fig. 2

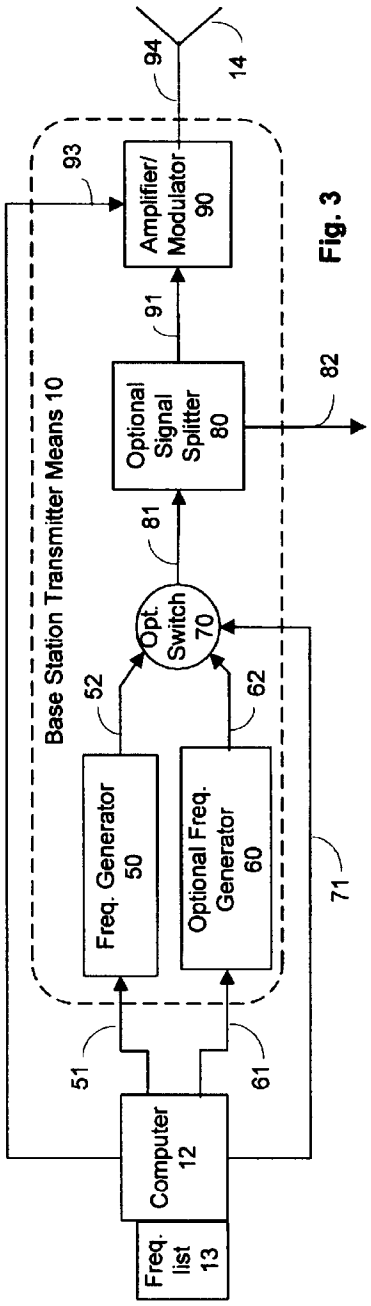


Fig. 3

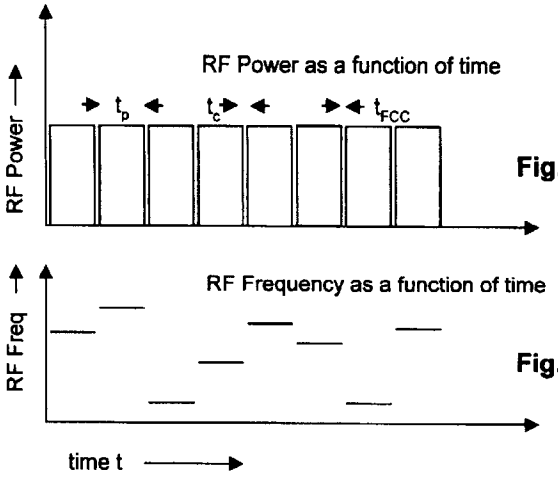


Fig. 4a

Fig. 4b

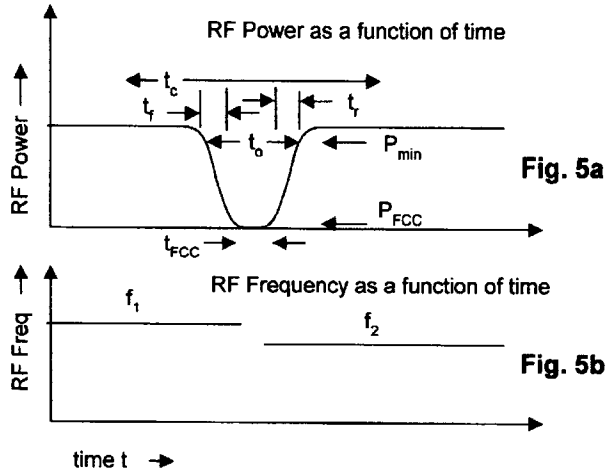


Fig. 5a

Fig. 5b

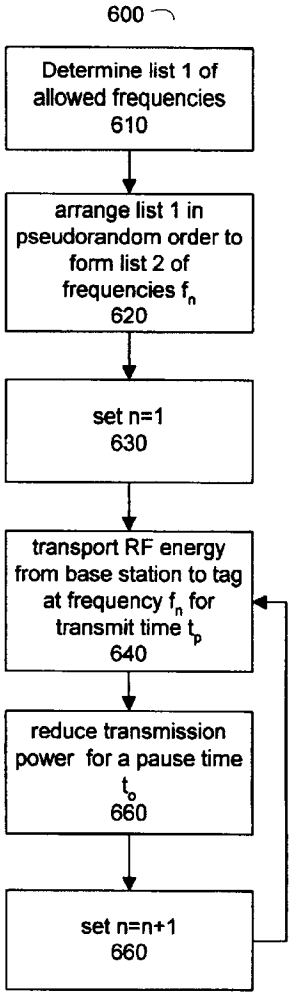


Fig. 6

METHOD OF TRANSPORTING RADIO FREQUENCY POWER TO ENERGIZE RADIO FREQUENCY IDENTIFICATION TRANSPONDERS

RELATED PATENT APPLICATIONS

Patent applications assigned to the assignee of the present invention: Ser. No. 08/303,965 filed Sep. 9, 1994 entitled "System and Method for Radio Frequency Tag Group Select", by Cesar et al.(now U.S. Pat. No. 5,673,037 issued Sep. 30, 1997); Ser. No. 08/304,340 filed Sep. 9, 1994 entitled Multiple Item Radio Frequency Tag Identification Protocol", by Chan et al., (now U.S. Pat. No. 5,550,547 issued Aug. 27, 1996); and Ser. No. 08/621,784, filed on Mar. 25, 1996 entitled "Thin Radio Frequency Transponder with Lead Frame Antenna Structure" by Brady et al. (pending) are hereby incorporated by reference.

BACKGROUND OF THE INVENTION 1. Field of the invention.

The field of the invention is the field of Radio Frequency (RF) transmission of power to supply energy to remote electronic equipment, especially equipment for the location, identification, and measurement of objects, items, animals, or people associated with RF transponders.

2. Description of the prior art.

RF Transponders (RF Tags) can be used in a multiplicity of ways for locating and identifying accompanying objects and transmitting information about the state of the object. It has been known since the early 60's in U.S. Pat. No. 3,098,971 by R.M. Richardson, that electronic components of transponders could be powered by radio frequency (RF) electromagnetic (EM) waves sent by a "base station" and received by a tag antenna on the transponder. The RF EM field induces an alternating current in the transponder antenna which can be rectified by an RF diode on the transponder, and the rectified current can be used for a power supply for the electronic components of the transponder. The transponder antenna loading is changed by something that was to be measured, for example a microphone resistance in the cited patent. The oscillating current induced in the transponder antenna from the incoming RF energy would thus be changed, and the change in the oscillating current led to a change in the RF power radiated from the transponder antenna. This change in the radiated power from the transponder antenna could be picked up by the base station antenna and thus the microphone would in effect broadcast power without itself having a self contained power supply. The "rebroadcast" of the incoming RF energy is conventionally called "back scattering", even though the transponder broadcasts the energy in a pattern determined solely by the transponder antenna. Since this type of transponder carries no power supply of its own, it is called a "passive" transponder to distinguish it from a transponder containing a battery or other energy supply, conventionally called an active transponder.

Active transponders with batteries or other independent energy storage and supply means such as fuel cells, solar cells, radioactive energy sources etc. can carry enough energy to energize logic, memory, and tag antenna control circuits. However, the usual problems with life and expense limit the usefulness of such transponders.

In the 70's, suggestions to use backscatter transponders with memories were made. In this way, the transponder could not only be used to measure some characteristic, for example the temperature of an animal in U.S. Pat. No. 4,075,632 to Baldwin et. al., but could also identify the animal.

The continuing march of semiconductor technology to smaller, faster, and less power hungry has allowed enormous increases of function and enormous drop of cost of such transponders. Presently available research and development technology will also allow new function and different products in communications technology. However, the new functions allowed and desired consume more and more power, even though the individual components consume less power.

It is thus of increasing importance to be able to power the transponders adequately and increase the range which at which they can be used. One method of powering the transponders suggested is to send information back and forth to the transponder using normal RF techniques and to transport power by some means other than the RF power at the communications frequency. However, such means require use of possibly two tag antennas or more complicated electronics.

Sending a swept frequency to a transponder was suggested in U.S. Pat. No. 3,774,205. The transponder would have elements resonant at different frequencies connected to the tag antenna, so that when the frequency swept over one of the resonances, the tag antenna response would change, and the backscattered signal could be picked up and the resonance pattern detected.

Prior art systems can interrogate the tags if more than one tag is in the field. U.S. Pat. No. 5,214,410, hereby incorporated by reference, teaches a method for a base station to communicate with a plurality of tags .

Sending at least two frequencies from at least two antennas to avoid the "dead spots" caused by reflection of the RF was proposed in EPO 598 624 A1, by Marsh et al. The two frequencies would be transmitted simultaneously, so that a transponder in the "dead spot" of one frequency would never be without power and lose its memory of the preceding transaction.

The prior art teaches a method to interrogate a plurality of tags in the field of the base station. The tags are energized, and send a response signal at random times. If the base station can read a tag unimpeded by signals from other tags, the base station interrupts the interrogation signal, and the tag which is sending and has been identified, shuts down. The process continues until all tags in the field have been identified. If the number of possible tags in the field is large, this process can take a very long time. The average time between the random responses of the tags must be set very long so that there is a reasonable probability that a tag can communicate in a time window free of interference from the other tags.

In order that the prior art methods of communicating with a multiplicity of tags can be carried out, it is important that the tags continue to receive power for the tag electronics during the entire communication period. If the power reception is interrupted for a length of time which exceeds the energy storage time of the tag power supply, the tag "loses" the memory that it was turned off from communication, and will restart trying to communicate with the base station, and interfere with the orderly communication between the base station and the multiplicity of tags.

The amount of power that can be broadcast in each RF band is severely limited by law and regulation to avoid interference between two users of the electromagnetic spectrum. For some particular RF bands, there are two limits on the power radiated. One limit is a limit on the continuously radiated power in a particular bandwidth, and another limit is a limit on peak power. The amount of power that can be pulsed in a particular frequency band for a short time is much higher than that which can be broadcast continuously.

Federal Communications Commission Regulation 15.247 and 15.249 of Apr. 25, 1989 (47 C.F.R. 15.247 and 15.249) regulates the communications transmissions on bands 902–928 MHZ, 2400–2483.5 MHZ, and 5725–5850 MHZ. In this section, intentional communications transmitters are allowed to communicate to a receiver by frequently changing frequencies on both the transmitter and the receiver in synchronism or by "spreading out" the power over a broader bandwidth. The receiver is, however, required to change the reception frequency in synchronism with the transmitter.

OBJECTS OF THE INVENTION

It is an object of the invention to provide an improved system, apparatus, and method to transport RF power to an RF transponder.

It is further a object of the invention to transport RF power to an RF transponder which contains an independent power means in order to "switch on" the independent power means.

SUMMARY OF THE INVENTION

The present invention is an apparatus, a system, and a method to use a "hopping frequency" signal to power remote electronic equipment such as RF transponders. In essence, an RF transmitter broadcasts a series of high power pulses, where the frequency of each pulse is chosen in order from a pseudo randomly ordered list of allowed frequencies. The transponders are able to receive power at all the frequencies sent. The energy received is stored in an energy store on the tag.

The time between pulses must be shorter than the time taken for the tag electronics to deplete the energy store on the tag.

The transponder could be passive or active, and the power transported to an active transponder could be used to activate a switching means to switch on the active power source when the transponder is in the range of the base station transmitter, and thus save the battery energy which would not be needed to "listen for" the communications when the transponder was not in the range of the transmitter of the base station.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for transporting RF power to an RF transponder.

FIG. **2** is a block diagram of an RF transponder having an independent power means and a switching means for switching on the independent power means when the switching means is energized by the transported RF power or, alternatively, when a part of the tag electronics is energized by the transported RF power.

FIG. **3** is block diagram of an alternative preferred apparatus of the invention.

FIG. **4***a* is the power and FIG. **4***b* is the frequency transmitted as a function of time in one of the preferred methods of the invention.

FIG. **5***a* is the power and fig. **5***b* is the frequency transmitted as a function of time in one of the preferred methods of the invention.

FIG. **6** is a block diagram of an alternative preferred method of the invention.

DETAILED DESCRIPTION OF THE INVENTION

A method of transporting power to a remote antenna connected to electronic circuitry for the purpose of energizing the electronic circuitry is proposed. A preferred embodiment is to transport power to an RF Identification and Location transponder (RFID Transponder) having logic circuits, memory circuits, and antenna impedance control circuits. The memory circuits can be written and read remotely. Examples of preferred RFID transponders and base stations are given in U.S. Pat. No. 4,656,463 issued on Apr. 7, 1987 by Anders et. al., which patent is hereby incorporated by reference.

FIG. **1** is a block diagram outlining the apparatus needed for implementing the method of the invention. A base station transmitter **10** is controlled by computer means **12** to send various frequencies and amplitudes of RF energy to base station antenna **14**. Antenna **14** radiates an RF electromagnetic wave **15** which causes a current to oscillate in tag antenna **16** of the transponder (tag) **17** receiving the RF power. A voltage rectifying power circuit **18** connected to tag antenna **16** provides power to energy store **19** while the RF energy **15** is being broadcast. Energy store **19** can be any means known in the art for storing energy, but is typically a capacitor on a semiconductor chip. Energy store **19** supplies energy to the electronic circuitry **20**. Electronic circuitry **20** may contain communication circuitry for receiving communications sent from the base station in the form of modulations of the RF energy and/or frequency. Electronic circuitry **20** may contain a read only memory and/or a read write memory and/or a means for changing the loading on the tag antenna in order to change the back scattering characteristics of the tag antenna for purposes of communication with the base station. Computer **12** may also be used to receive, analyze, store, and communicate data sent by the base station transmitter **10** to the transponder. Computer **12** may also receive and communicate data sent by the tag to a receiver (not shown). The tag requires both power to operate, and a minimum voltage to run the semiconductor devices in the tag electronics **20**. It is important that the voltage supplied by the tag energy store **19** not drop below a threshold level during the tag communication protocol. If the RF energy **15** transmitted from the base station antenna **14** is stopped, the energy stored in the tag energy store **19** is depleted in a characteristic time t. which depends on the capacity of the tag energy store **19**, the amount of energy actually stored in the tag energy store **19**, (since the tag may be in a range from the base station where the energy store is not fully charged) and the power demands of circuitry **20**. The capacity of the tag energy store can be made quite large, but for low cost tags, it should be in the range of the energy storage capacitance of capacitors formed by normal electronics technology used for semiconductor chips. More capacitance takes more area on the chip, and is more costly. It is necessary that the RF transmission of energy not be interrupted for a time to greater than the critical time t_c. It is preferable that the RF transmission of energy be interrupted for a time t_o less than 400 milliseconds. It is more preferable that the transmission be interrupted for a time t_o less than 400 microseconds, even more preferable that the transmission be interrupted for a time t_o less than 50 microseconds, and most preferable that the transmission be interrupted for a time t_o less than 30 microseconds. (See discussion of FIG. **5** below),

FIG. **2** shows a block diagram of the apparatus for implementing a preferred method of the invention where the tag **17** is an active tag which contains an energy supply means **22** such as a battery and a switch means **24** for connecting the energy supply means **22** to the tag electronics **20** when the switch means **24** is energized by the voltage rectifying power circuit **18** and the energy store **19**. Elec-

tronic circuitry decision means **26** which is part of the tag electronics **20** may alternatively be energized by the voltage rectifying power circuit **18**, and decision means **26** may decide on the basis of the power received by the energy supply means **22** to fully energize electronic circuitry **20** by connecting energy supply means **22** with the tag electronics through switch means **24**.

In one preferred method of the invention, the frequency sent out from the base station must be changed over time. However, if the frequency is changed slowly from a first frequency f_1 to a second frequency f_2, the sent out frequency passes through a number of other frequencies in between f_1 and f_2. If the frequency is changed very rapidly, a large bandwidth of frequencies is generated, with the bandwidth center sweeping from f_1 to f_2 over time. Both of these results would result in possible interference with other users of the spectrum, which is prohibited by FCC regulations. A preferred method is to turn off the transmitter or reduce the power of the transmitter while the frequency change is taking place.

However, the tag relies on the sent out power to keep critical functions, such as its "short term memory", active while the tag and the base station are in communication with each other. Other critical functions of the tag which would be affected by loss of power are the "clock signal" which would be lost and a "tag state" which would be changed. Loss of the "short term memory" would seriously affect communication protocols for the tag, IE. the multiple tag communication protocols referred to above. It is critical that the power be turned off for a very short time.

A base station transmitter **10** for transporting RF power to RF transponders shown in FIG. **3** enables sending out two different frequency pulses separated by a very short time, specifically less than t_c. In one embodiment, a single RF generator **50** is used to sequentially generate two different RF frequencies f_1 and f_2 under control of the computer **12** over line **51**. RF generator **50** can switch frequencies in a time less than the time t_c which is taken for the tag energy store **19** to be drained to a level where a critical tag function is impaired. When RF generator **50** is switching frequency, amplifier/modulator unit **90** is switched off under control of computer **12** over line **93**. RF generators **50** (and **60**) and RF amplifier/modulators are well known.

In another preferred embodiment, one or more additional optional RF generators **60** are included in the base station transmitter means **10**. This is an innovative apparatus for providing a fast means for changing the RF frequency of signals sent by a base station to RF tags. Optional RF switch **70** is controlled by computer **12** over line **71** to switch either RF generator **50** or optional RF generator **60** to the rest of the base station transmitter **10**.

For a time t p RF generator **50** is connected via lines **81** and **52** through switch **70** to an optional signal splitter **80** which divides the RF signal coming from the switch **70**. A small part of the RF energy from RF generator **50** is tapped off in splitter **80** to be sent to an RF receiver (not shown) via line **82**. (The RF receiver uses the frequency as a comparison to detect the backscattered radiation from the tags.) Most of the RF energy from RF generator **50** is sent to amplifier modulator module **90** via line **91**. Amplifier/Modulator module **90** is controlled via line **93** by computer **12**, and sends amplified and optionally modulated RF energy over line **94** to antenna **14**.

When the base station transmitter **10** is transmitting power to the tag **17**, and shown here for simplicity as not sending a modulated communication signal, the RF power and the RF frequency as a function of time are shown in FIG. **4**a and FIG. **4**b respectively. The RF power is on for a pulse time t_p of 300 to 400 milliseconds, for an RF frequency approximately 2.4 Ghz. Then, the power is reduced to a very small amount, which is preferably zero. During part of the time that the computer **12** instructs the amplifier/modulator **90** to cease amplification, a power that is lower than an FCC power limit P_{FCC}, defined as the maximum power that can be sent out of frequency channel being used, is sent out from antenna **14** during a time t_{FCC}, The computer instructs switch **70** to switch from frequency generator **50** to frequency generator **60** during the time t_{FCC}, Well known RF switches such as switch **70** can easily switch from one source to the other in less than a microsecond. During the time t_p which RF generator **50** has been sending RF power at frequency f, to the amplifier, frequency generator **60** has had ample time to change frequencies to frequency f_2 from its previous frequency.

After the computer commands switch **70** to change the amplifier connection from RF generator **50** to RF generator **60**, a frequency is chosen from a frequency list **13** stored in the computer memory or other memory location to be the next frequency to be transmitted, and instructs RF generator **50** to set itself to the next frequency required after frequency f2 so that the sent out frequency can again be changed during the next power off time. The computer then instructs modulator **90** to amplify once again and send the next pulse of RF power to antenna **14**. After the time t_p, the RF generator **50** has settled to the new frequency and the switch **70** switches back to generator **50** during the time the amplifier **90** is turned off again.

The transmitted RF power and frequency during a changeover are shown in FIG. **5***a* and **5***b*respectively. The rise time t_r and fall time t_f of the power during the switching are very important. When the RF power is switched off and on, side bands of frequencies f_1 and f_2 respectively will be generated and sent to the antenna **14**. The allowed frequency broadening depends on the frequency bands used. If the frequency broadening is too great, the sidebands may cause interference, which is not allowed. The frequency broadening becomes greater as t_1 and t_f are reduced. There is thus a limit below which t_1 and t_f may not be reduced. Thus, the off time t_o during which the RF power sent out is reduced below power P_{min}, where P_{min} is the power which can sustain the energy in the tag energy store **19** above the level needed by the tag electronics **20**, must be greater than t_{FCC} plus the time taken to reduce power from P_{min} to P_{FCC} plus the time taken to raise the power again from P_{FCC} to P_{min}. For example, in the 2.4 Ghz band, the off time t_o must be longer than approximately 700 nanoseconds to allow for both the rise and fall times shown in FIG. **5***a*. More preferably, the off time is longer than 10 microseconds.

This means that the off time t_o must be shorter than a first limit time because the tag will lose memory or other tag function, and longer than a second limit time, so that the frequency sent may change without introducing interfering levels of RF power outside the allowed channels.

The frequency shifts of the transmitter can be random or can be programmed to a particular pattern such as a ramp or stair step pattern which used sufficient frequencies in the bandwidth that the limits on average power in a particular frequency would not exceed regulations. A pseudo random pattern is the most preferred pattern.

A preferred method of the invention is given by the flow chart **600** in FIG. **6**, and comprises the steps of:

610 Determining a first list of a large plurality of allowed frequencies.

620 Optionally arranging the first list of the large plurality of allowed frequencies as a pseudo randomly ordered second list of a large plurality of allowed frequencies f_n.

630 Initializing the process by setting n=1.

640 Transporting RF power for a time t_p from a base station to a radio frequency transponder at a frequency f_n chosen from the random ordered second list of large plurality of allowed frequencies.

650 Ceasing to transmit power for a time t_o.

660 Setting n=n+1 and returning to step **640**.

Given this disclosure, alternative equivalent embodiments would become apparent to one skilled in the arts that are within the contemplation of the inventors. For example, different times t_p for different frequencies, and different off times t_o, as long as the pauses in the power transmission are less than that time which would affect critical electronic components of the tag, are foreseen.

We claim:

1. A method of transporting Radio Frequency (RF) energy to an RF transponder (RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising the steps of:

(a) transporting for a first time RF electromagnetic wave energy from a base station having a base station antenna to the RF tag, the RF energy having a first frequency f_1;then

(b) ceasing to transport RF energy during an off time t_o, where the off time t_o is less than a time where the RF tag loses one or more functions; and then

(c) transporting for a second time RF electromagnetic wave energy from the base station to the RF tag, the RF energy having a second frequency f_2 different from the first frequency f_1, the tag antenna and the rectifying circuit of the RF tag being adapted for receiving power at frequencies f_1 and f_2.

2. The method of claim **1**, wherein the off time t_o is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

3. The method of claim **1**, wherein steps a to c are repeated with different frequencies f_1 and f_2.

4. The method of claim **3**, wherein steps a to c are repeated a large number of times with a large plurality of different frequencies chosen in order from a randomly ordered list of different frequencies.

5. The method of claim **4**, where the off time t_o is less than 400 milliseconds.

6. The method of claim **5**, where the off time t_o is less than 400 microseconds.

7. The method of claim **6**, where the off time t_o is less than 50 microseconds.

8. The method of claim **1**, wherein the RF tag further comprises:

and independent source of energy; and

a switching means responsive to the RF energy transported to the tag adapted to connect the independent source of energy to the tag electronics when RF energy is transported to the tag.

9. The method of claim **8**, wherein the switching means is controlled by a tag decision means responsive to the RF energy transported to the tag.

10. A method of transporting Radio Frequency (RF) energy to an RF transponder (RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising the steps of:

a) determining a list of a large plurality of different frequencies;

b) transporting RF electromagnetic wave energy for a first time from a base station to the remote RF tag at a first frequency chosen from the list of large plurality of different frequencies;

c) ceasing to transport RF energy during an off time t_o, where the off time is less than a time where the tag loses one or more functions;

d) repeating steps b) and c) using frequencies chosen in order from the list.

11. The method of claim **10**, wherein the list is a list of frequencies in pseudo random order.

12. The method of claim **11**, wherein the tag antenna and the rectifying circuit of the remote RF tag are adapted to receive energy transmitted at each frequency of the list of frequencies in pseudo random order.

13. A base station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending RF signal;

an RF amplifier/modulator for receiving the RF signal and for sending RF power to antenna; and

a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where the RF tag energy store is depleted so that the tag electronics do not function.

14. The base station of claim **13**, wherein the RF generator comprises:

a first RF generator for generating the frequency f_1;

a second RF generator for generating the frequency f_2; and

and RF switch, wherein the computer controls the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator.

15. The bases station of claim **13**, where the time during which the power is reduced is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

16. The base station of claim **13**, where the time during which the power is reduced is less than 400 milliseconds.

17. The base station of claim **16**, where the time during which the power is reduced is less than 400 microseconds.

18. The base station of claim **17**, where the time during which the power is reduced is less than 50 microseconds.

19. A system for transporting RF energy from a base station to one or more remote RF tags, comprising:

an RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving

energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics; and

a base station comprising an RF generator, and RF amplifier/modulator for sending RF power to an antenna; and a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier /modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where the RF tag loses one or more functions.

20. The system of claim **19**, where the RF generator comprises:

a first RF generator for generating the frequency f_1;

a second RF generator for generating the frequency f_2;

an RF switch, wherein the computer controls the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator.

21. The system of claim **19**, where the time during which the power is reduced is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

22. The system of claim **19**, where the time during which the power is reduced is less than 400 milliseconds.

23. The system of claim **22**, where the time during which the power is reduced is less than 400 microseconds.

24. The system of claim **23**, where the time during which the power is reduced is less than 50 microseconds.

25. The system of claim **19**, where the RF generator comprises:

a first RF generator for generating the frequency f_1;

a second RF generator for generating the frequency f_2; and

an RF switch, wherein the computer controls the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator.

26. A base station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending an RF signal, where the RF generator comprises a first RF generator for generating a frequency f_1, a second RF generator for generating a frequency f_2, and an RF switch;

an RF amplifier/modulator for receiving the RF signal and for sending RF power to an antenna;

and

a computer, the computer controlling the RF generator to change from the first frequency f_1 to the second frequency f_2 controlling the RF switch to switch the input of the RF amplifier/modulator from the output of the first RF generator to the output of the second RF generator, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced less than the time where the RF tag loses one or more functions.

27. A bases station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending RF signal;

an RF amplifier/modulator for receiving the RF signal and for sending RF power to an antenna;

and

a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where RF tag loses one or more functions and the time during which the power is reduced is greater than a time when a sideband of f_1 is generated, the sideband of f_1 having a frequency and power forbidden by government regulation.

28. A base station for transporting Radio Frequency (RF) energy to an RF tag, the RF tag comprising at least one tag antenna, a rectifying circuit connected to the tag antenna for receiving energy from the tag antenna, a tag energy store for storing the energy received from the rectifying circuit, tag electronics, and means for delivering energy from the tag energy store to the tag electronics, comprising:

an RF generator for sending an RF signal;

an RF amplifier/modulator for receiving the RF signal for sending RF power to an antenna;

and

a computer, the computer controlling the RF generator to change from a first frequency f_1 to a second frequency f_2, the computer controlling the RF amplifier/modulator to reduce power sent to the antenna during the entire time the RF generator is changing from f_1 to f_2, where the time during which the power is reduced is less than the time where the RF tag loses one or more functions and the time during which the power is reduced is less than 400 milliseconds.

29. The base station of claim **28**, where the time during which the power is reduced is less than 400 microseconds.

30. The base station of claim **29**, where the time during which the power is reduced is less than 50 microseconds.

* * * * *

EXHIBIT H

US006286762B1

(12) **United States Patent**
Reynolds et al.

(10) **Patent No.: US 6,286,762 B1**
(45) **Date of Patent: Sep. 11, 2001**

(54) **METHOD AND APPARATUS TO PERFORM A PREDEFINED SEARCH ON DATA CARRIERS, SUCH AS RFID TAGS**

(75) Inventors: **Andrew E. Reynolds**, Bothell; **Christopher A. Wiklof**, Everett; **Daniel B. Bodnar**, Duvall, all of WA (US)

(73) Assignee: **Intermec IP Corp.**, Beverly Hills, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/401,363**

(22) Filed: **Sep. 21, 1999**

(51) **Int. Cl.**[7] **G06K 7/10**
(52) **U.S. Cl.** **235/472.01**; 235/472.02
(58) **Field of Search** 235/472.01, 472.02

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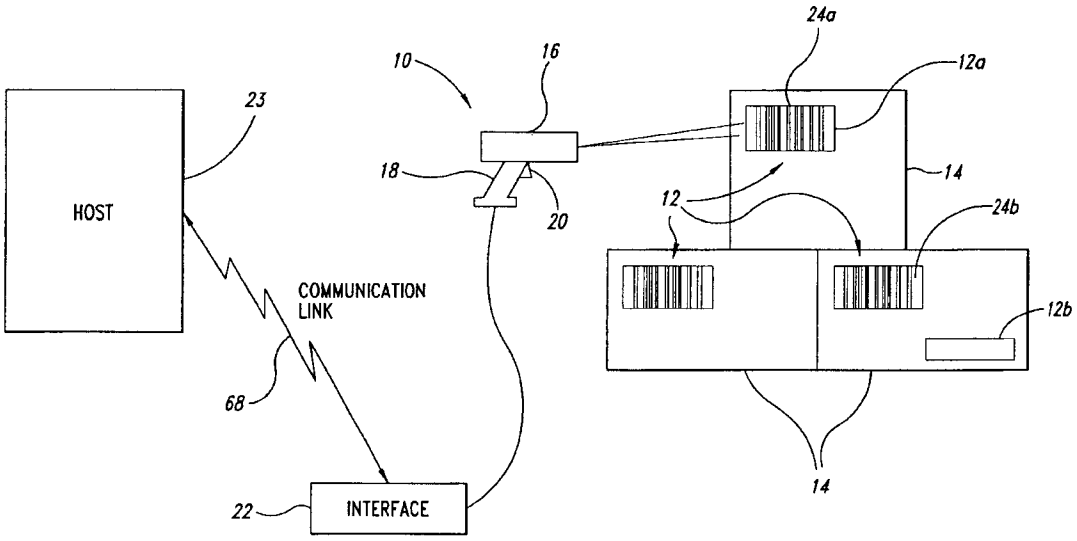
Primary Examiner—Harold I. Pitts
(74) *Attorney, Agent, or Firm*—Seed IP Law Group PLLC

(57) **ABSTRACT**

A data carrier reader is capable of executing a number of different reading methods. One method performs an inclusive search, identifying all RFID tags having a characteristic data string that appears on a list of characteristic data strings, for example, stored in a buffer. Another method performs and exclusive search, identifying any RFID tags having a characteristic data string that does not appear on the list. In each method, the data carrier reader provides a consistent and intuitive output the user to identify the successful and unsuccessful operations such as locating a desired RFID tag on the list or missing from the list.

9 Claims, 15 Drawing Sheets



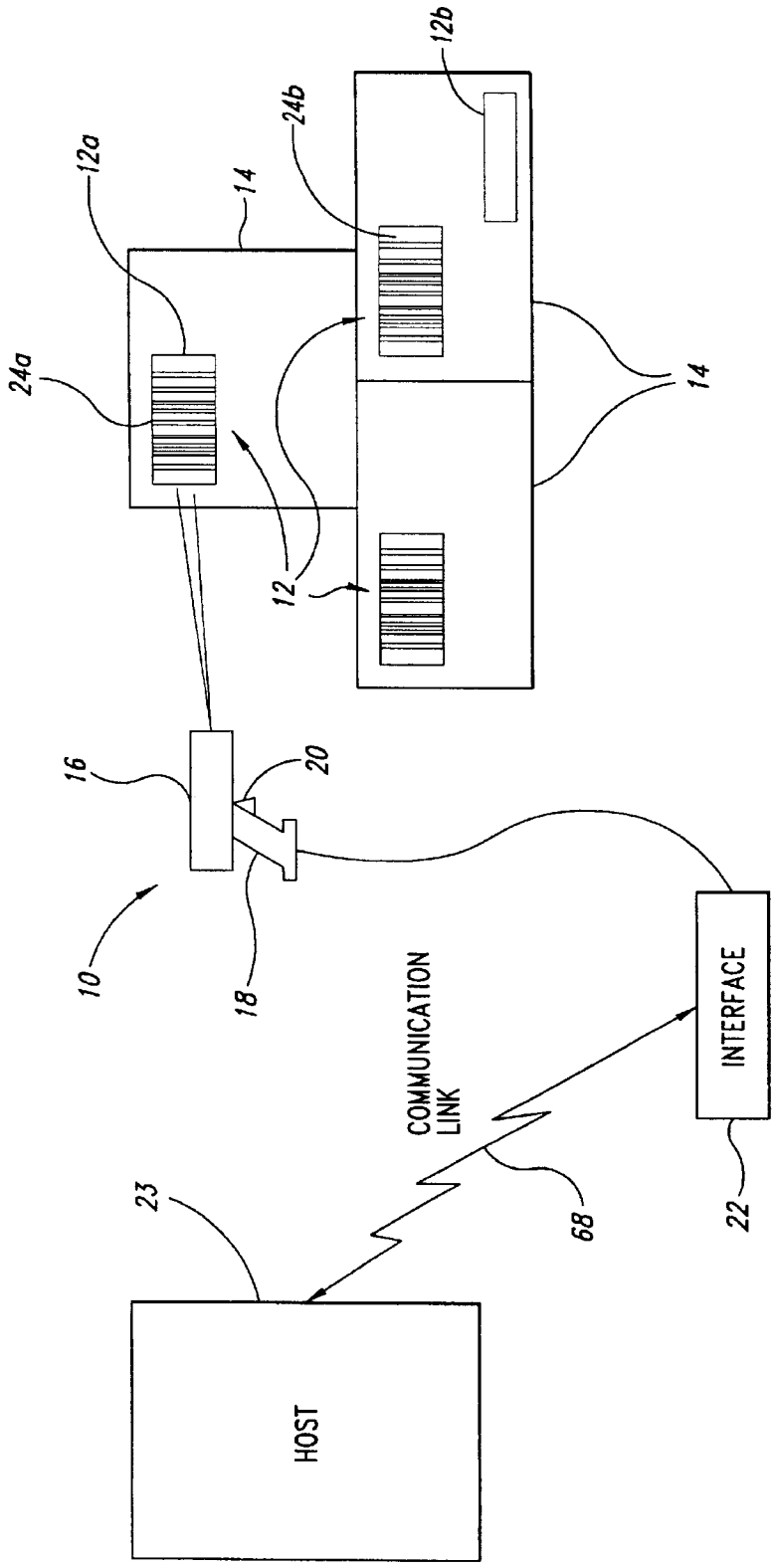

12b
24b
12a
14
24a
14
12
16
20
10
18
COMMUNICATION LINK
INTERFACE
23
68
22
HOST

Fig. 1

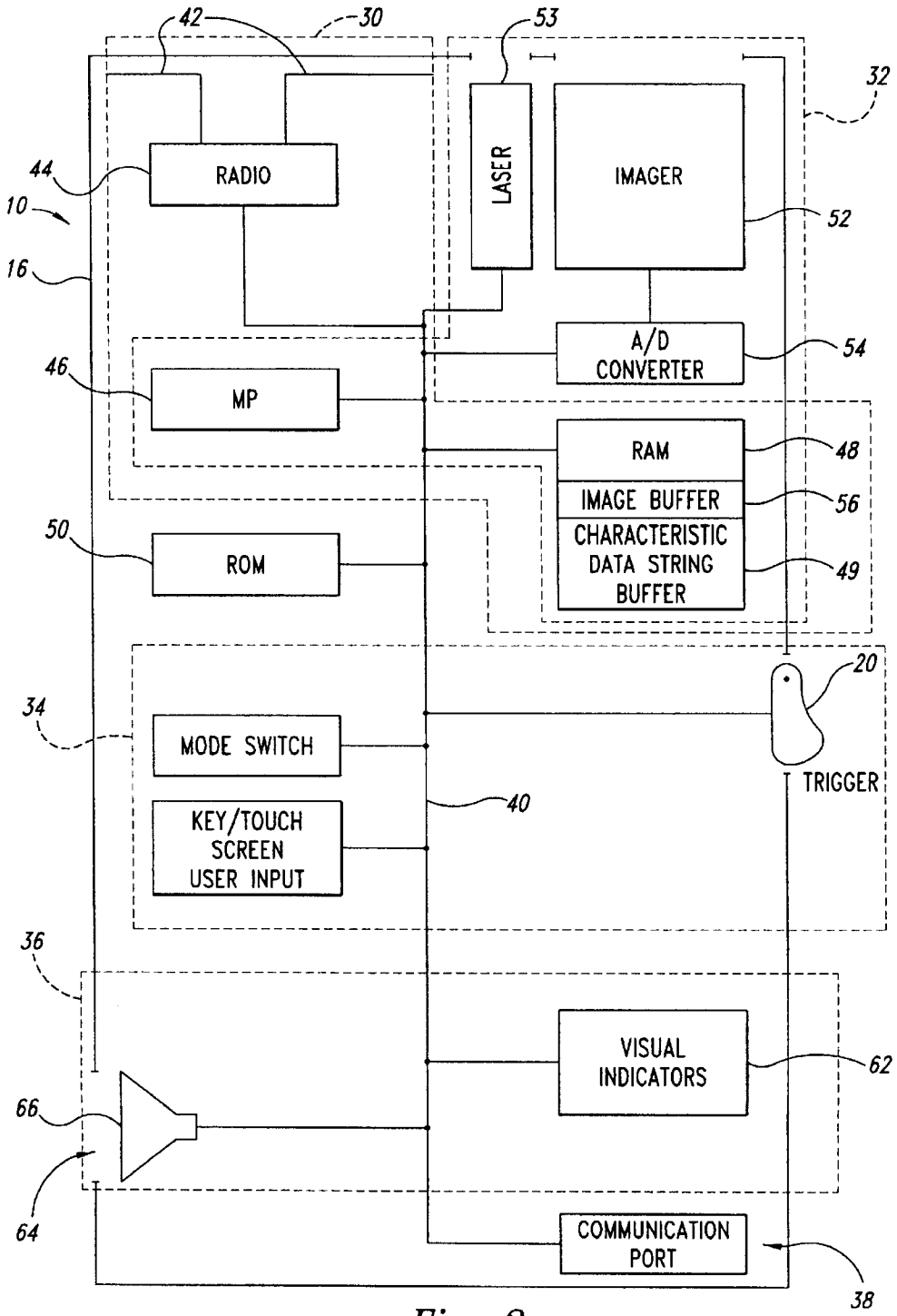

42
30
53
32
RADIO
LASER
IMAGER
44
10
52
16
A/D CONVERTER
54
46
MP
RAM
48
IMAGE BUFFER
56
CHARACTERISTIC DATA STRING BUFFER
49
50
ROM
20
34
MODE SWITCH
TRIGGER
40
KEY/TOUCH SCREEN USER INPUT
36
VISUAL INDICATORS
62
66
64
COMMUNICATION PORT
38

Fig. 2

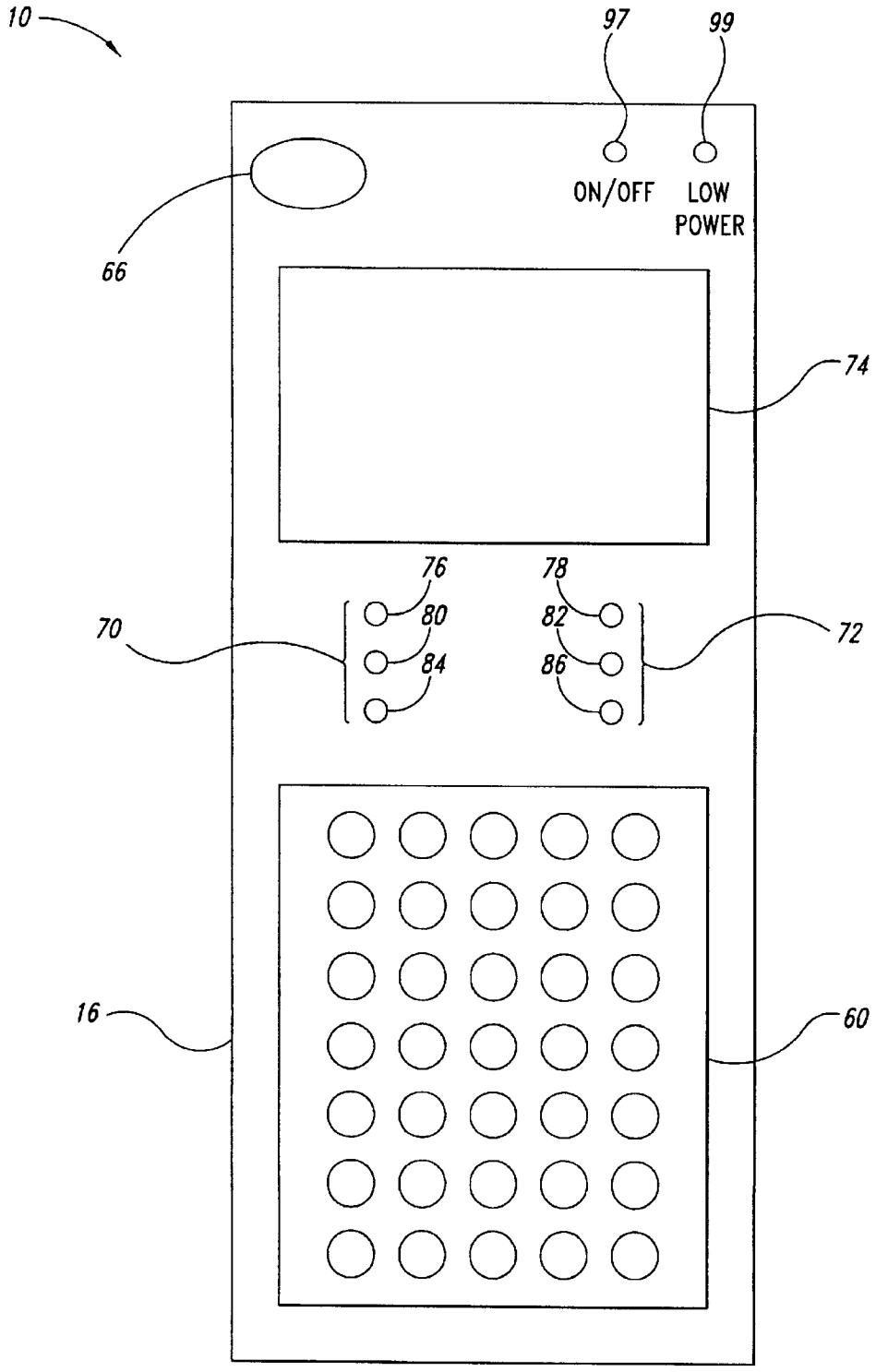


Fig. 3

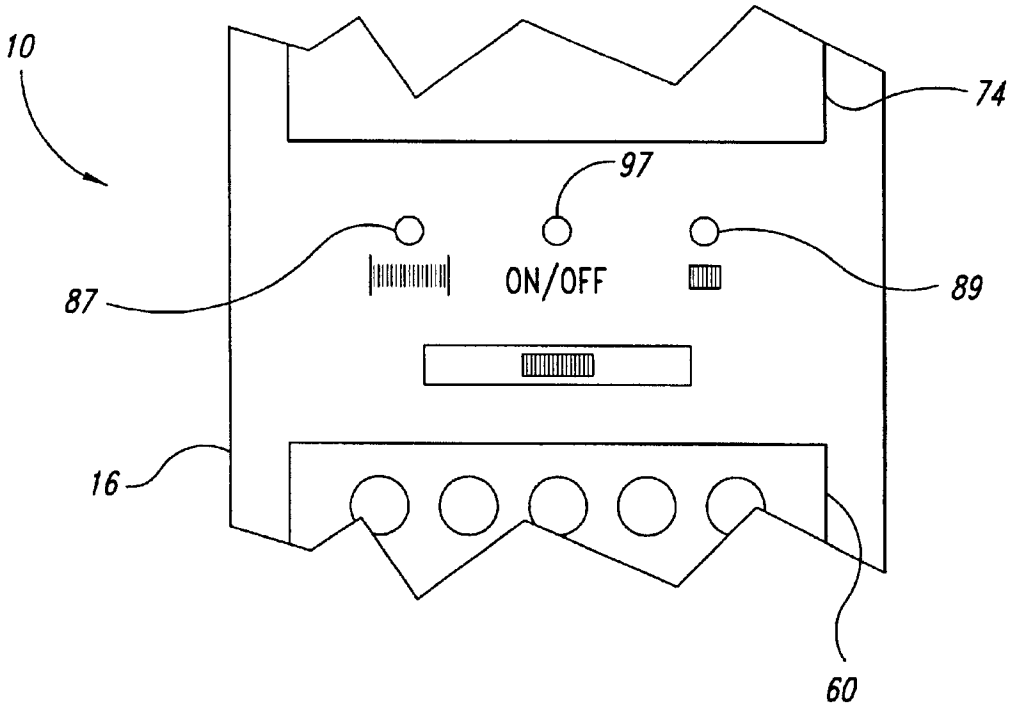
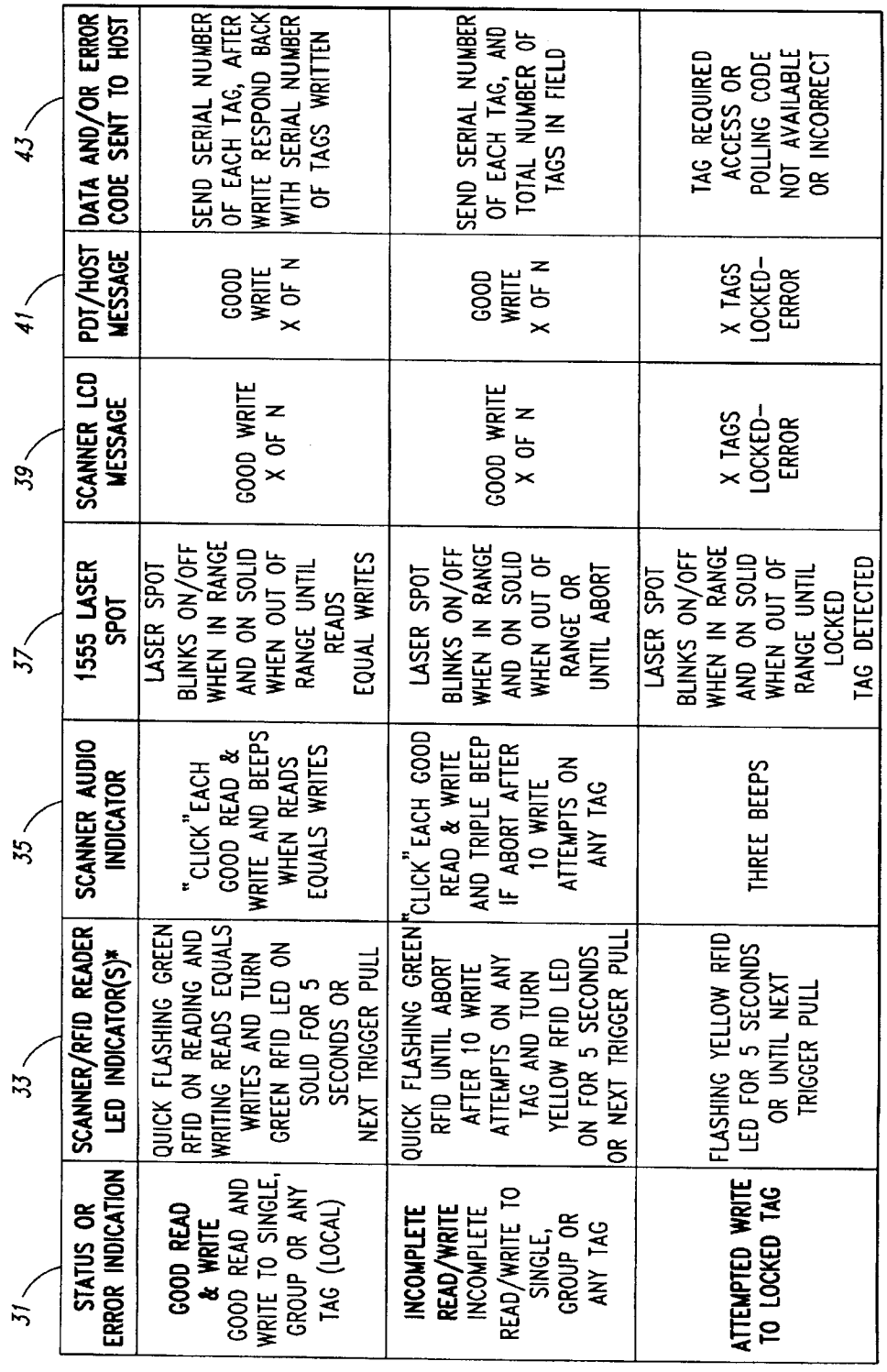


Fig. 4

31 STATUS OR ERROR INDICATION	33 SCANNER/RFID READER LED INDICATOR(S)*	35 SCANNER AUDIO INDICATOR	37 1555 LASER SPOT	39 SCANNER LCD MESSAGE	41 PDT/HOST MESSAGE	43 DATA AND/OR ERROR CODE SENT TO HOST
NO SCANNING OR RFID READING	NONE	NONE	OFF	NONE	NONE	NONE
ATTEMPT RFID READ OR WRITE OF TAGS	YELLOW RFID & POWER LED ON UNTIL SUCCESSFUL READ OR RELEASE OF TRIGGER	NONE	LASER SPOT FLASHING ON/OFF WHEN READING	GOOD READ 0	NONE	NONE
INTERROGATION TOO FAST (UNSUCCESSFUL INTERROGATION)	FLASHING YELLOW RFID LED UNTIL VALID RFID DECODES OR UNTIL TRIGGER IS OFF	CONTINUOUS "CLICKS"	LASER SPOT SOLID ON	"SCANNING TOO FAST"	"SCANNING TOO FAST"	NONE
BAR CODE SCANNING	YELLOW POWER LED ON UNTIL SUCCESSFUL DECODE OR RELEASE OF TRIGGER	NONE	OFF IN DEFAULT BUT CAN BE PROGRAMMED ON AND SET FOR SPECIFIED DURATION	NONE	NONE	NONE
BAR CODE SUCCESSFUL DECODE	GREEN BAR CODE LED ON FOR 5 SECONDS OR NEXT TRIGGER PULL, YELLOW POWER LED OFF	ONE BEEP	OFF	DISPLAY DATA	DISPLAY DATA	DATA

Fig. 5A



31 STATUS OR ERROR INDICATION	33 SCANNER/RFID READER LED INDICATOR(S)*	35 SCANNER AUDIO INDICATOR	37 1555 LASER SPOT	39 SCANNER LCD MESSAGE	41 PDT/HOST MESSAGE	43 DATA AND/OR ERROR CODE SENT TO HOST
GOOD READ & WRITE GOOD READ AND WRITE TO SINGLE, GROUP OR ANY TAG (LOCAL)	QUICK FLASHING GREEN RFID ON READING AND WRITING READS EQUALS WRITES AND TURN GREEN RFID LED ON SOLID FOR 5 SECONDS OR NEXT TRIGGER PULL	"CLICK" EACH GOOD READ & WRITE AND BEEPS WHEN READS EQUALS WRITES	LASER SPOT BLINKS ON/OFF WHEN IN RANGE AND ON SOLID WHEN OUT OF RANGE UNTIL READS EQUAL WRITES	GOOD WRITE X OF N	GOOD WRITE X OF N	SEND SERIAL NUMBER OF EACH TAG, AFTER WRITE RESPOND BACK WITH SERIAL NUMBER OF TAGS WRITTEN
INCOMPLETE READ/WRITE INCOMPLETE READ/WRITE TO SINGLE, GROUP OR ANY TAG	QUICK FLASHING GREEN RFID UNTIL ABORT AFTER 10 WRITE ATTEMPTS ON ANY TAG AND TURN YELLOW RFID LED ON FOR 5 SECONDS OR NEXT TRIGGER PULL	"CLICK" EACH GOOD READ & WRITE AND TRIPLE BEEP IF ABORT AFTER 10 WRITE ATTEMPTS ON ANY TAG	LASER SPOT BLINKS ON/OFF WHEN IN RANGE AND ON SOLID WHEN OUT OF RANGE OR UNTIL ABORT	GOOD WRITE X OF N	GOOD WRITE X OF N	SEND SERIAL NUMBER OF EACH TAG, AND TOTAL NUMBER OF TAGS IN FIELD
ATTEMPTED WRITE TO LOCKED TAG	FLASHING YELLOW RFID LED FOR 5 SECONDS OR UNTIL NEXT TRIGGER PULL	THREE BEEPS	LASER SPOT BLINKS ON/OFF WHEN IN RANGE AND ON SOLID WHEN OUT OF RANGE UNTIL LOCKED TAG DETECTED	X TAGS LOCKED-ERROR	X TAGS LOCKED-ERROR	TAG REQUIRED ACCESS OR POLLING CODE NOT AVAILABLE OR INCORRECT

Fig. 5B

31 STATUS OR ERROR INDICATION	33 SCANNER/RFID READER LED INDICATOR(S)*	35 SCANNER AUDIO INDICATOR	37 1555 LASER SPOT	39 SCANNER LCD MESSAGE	41 PDT/HOST MESSAGE	43 DATA AND/OR ERROR CODE SENT TO HOST
SEARCH FOR MATCHES SEARCH FOR MATCHES WHERE TRIGGER BECOMES ON/OFF TOGGLE SWITCH, i.e., FIRST TRIGGER ACTIVATION TURNS ON AND SECOND TRIGGER ACTIVATION TURNS OFF.	YELLOW LED FLASH ON NON-MATCH. QUICK GREEN FLASHING LED TO EVERY MATCH. HOST PROVIDED SORT TABLE. HOST OR BAR CODE PROGRAMMABLE FOR MATCH OR EXCEPTION.	"CLICK" FOR EACH NON-MATCH AND BEEP FOR EACH MATCH. BEEPER SET TO DEFAULT.	LASER SPOT BLINKS ON/OFF WHEN IN RANGE AND ON SOLID WHEN OUT OF RANGE. FLASHES FASTER WHEN FINDS A MATCH.	"SEARCHING" FLASHING UNTIL "MATCH" ON TOP LINE OF LCD W/ HISTOGRAM SHOWING NUMBER OF NEW READS.	DISPLAY MATCHED DATA.	TRANSFER LIST FROM HOST, TRANSFER MATCHING DATA STRINGS TO HOST.
BUFFER FULL THIS STATUS APPLIES TO AN APPLICATION WHERE THE HAND HELD'S BUFFER BECOMES FULL WITH TAG DATA. FOR EXAMPLE, IN AN INVENTORY OPERATION WHERE A USER CONTINUOUSLY SCANS TAG DATA INTO THE HAND HELD. THE HAND HELD WILL BE UNTETHERED.	YELLOW LED SOLID FOR 5 SECONDS OR UNTIL NEXT USER ENTRY.	TRIPLE BEEP UPON ANY ATTEMPT TO ADD MORE DATA TO THE BUFFER UNTIL IT HAS BEEN UPLOADED OR RESET.	NONE	BUFFER FULL	N/A	TRANSFER DATA FROM BUFFER TO HOST.

Fig. 5C

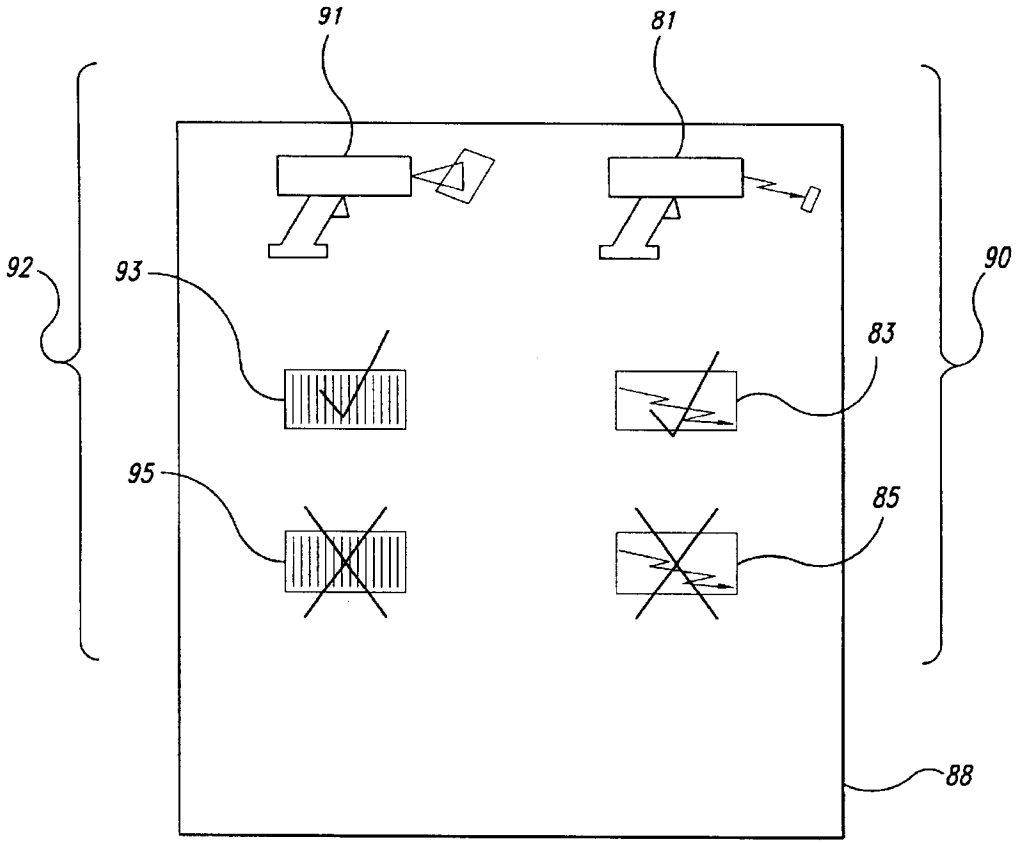

91
81
92
93
90
83
95
85
88

Fig. 6

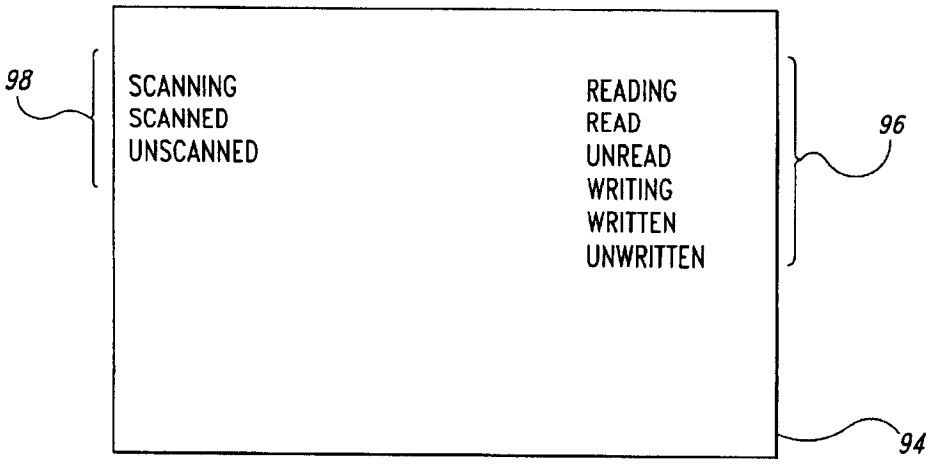

98
SCANNING
SCANNED
UNSCANNED
READING
READ
UNREAD
WRITING
WRITTEN
UNWRITTEN
96
94

Fig. 7

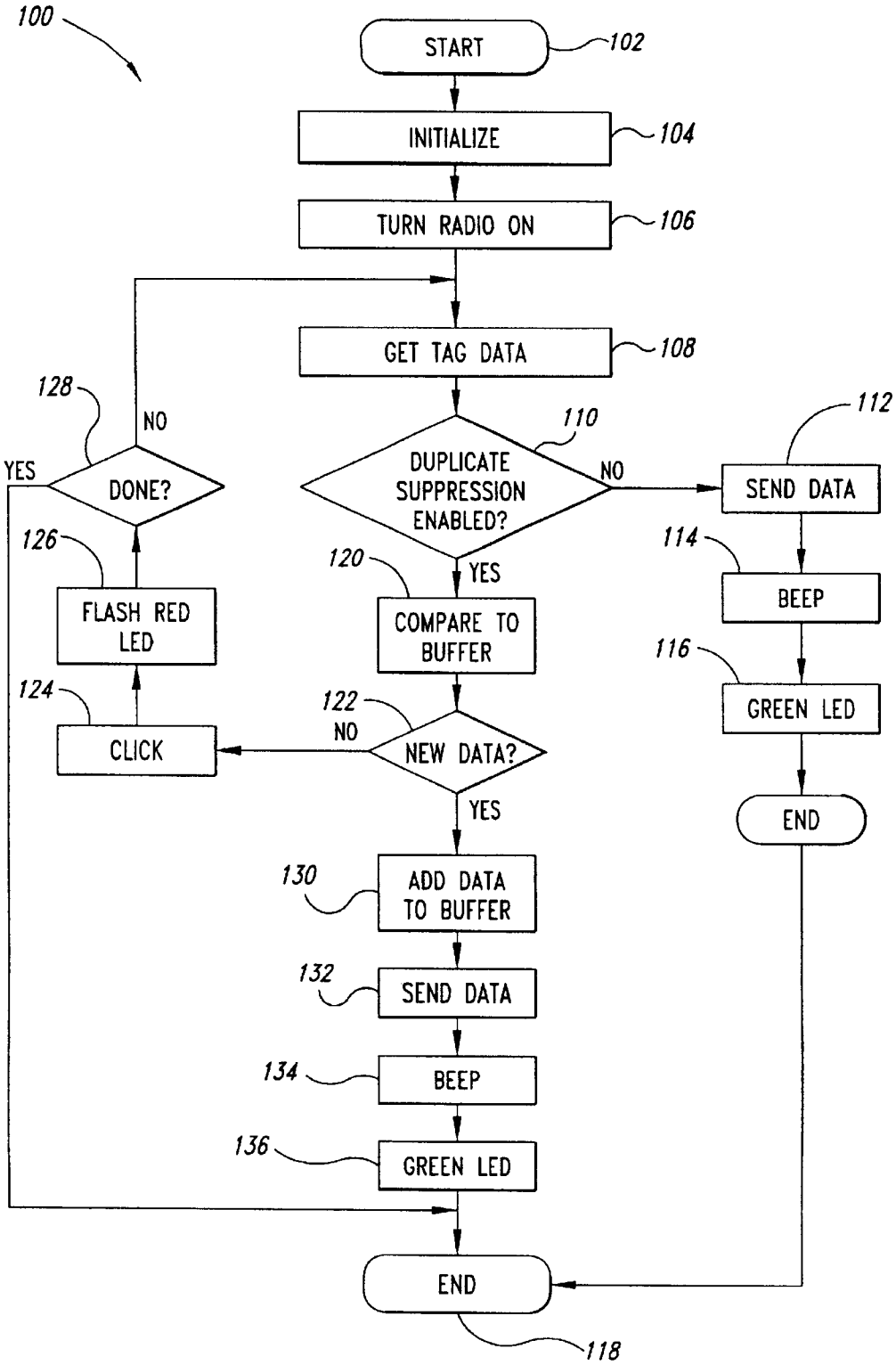

100
START
102
INITIALIZE
104
TURN RADIO ON
106
GET TAG DATA
108
DUPLICATE SUPPRESSION ENABLED?
110
NO
YES
SEND DATA
112
BEEP
114
GREEN LED
116
END
YES
COMPARE TO BUFFER
120
NEW DATA?
122
NO
CLICK
124
FLASH RED LED
126
DONE?
128
NO
YES
ADD DATA TO BUFFER
130
SEND DATA
132
BEEP
134
GREEN LED
136
END
118

Fig. 8

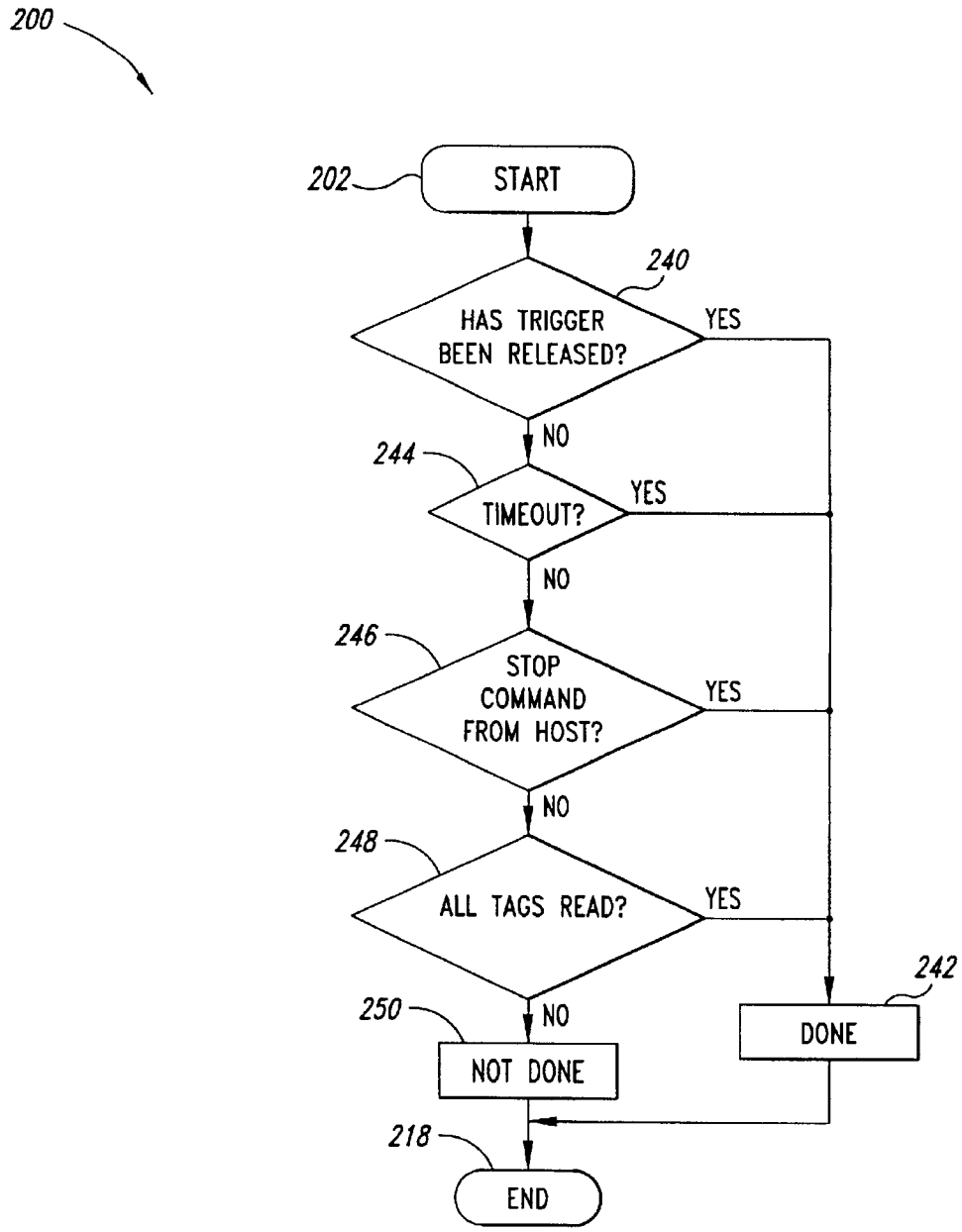

200
202
START
240
HAS TRIGGER BEEN RELEASED?
YES
NO
244
TIMEOUT?
YES
NO
246
STOP COMMAND FROM HOST?
YES
NO
248
ALL TAGS READ?
YES
NO
250
NOT DONE
242
DONE
218
END

Fig. 9

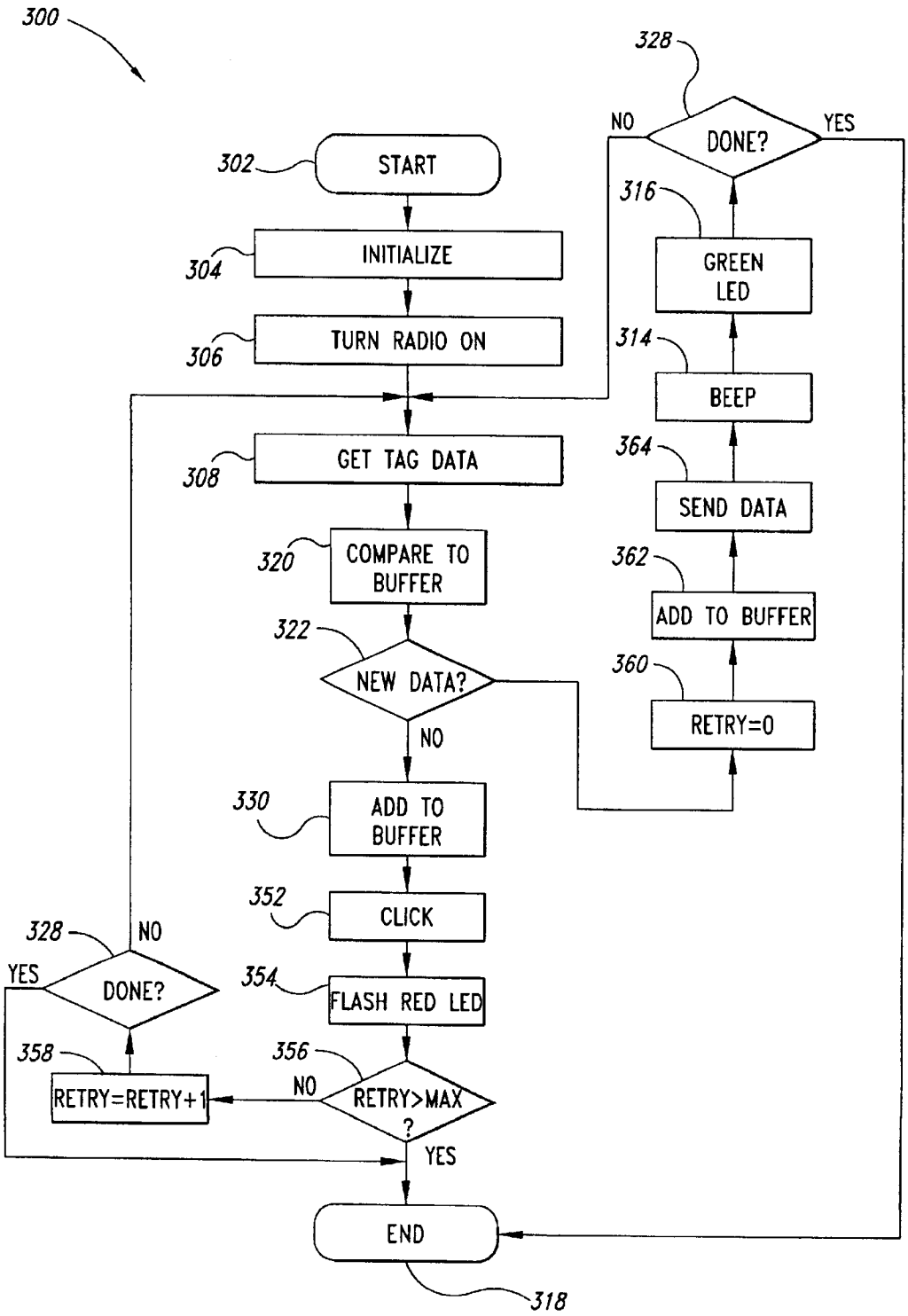

300
328
NO
DONE?
YES
302
START
316
GREEN LED
304
INITIALIZE
306
TURN RADIO ON
314
BEEP
308
GET TAG DATA
364
SEND DATA
320
COMPARE TO BUFFER
362
ADD TO BUFFER
322
NEW DATA?
360
RETRY=0
NO
330
ADD TO BUFFER
352
CLICK
328
NO
YES
DONE?
354
FLASH RED LED
358
356
RETRY=RETRY+1
NO
RETRY>MAX ?
YES
END
318

Fig. 10

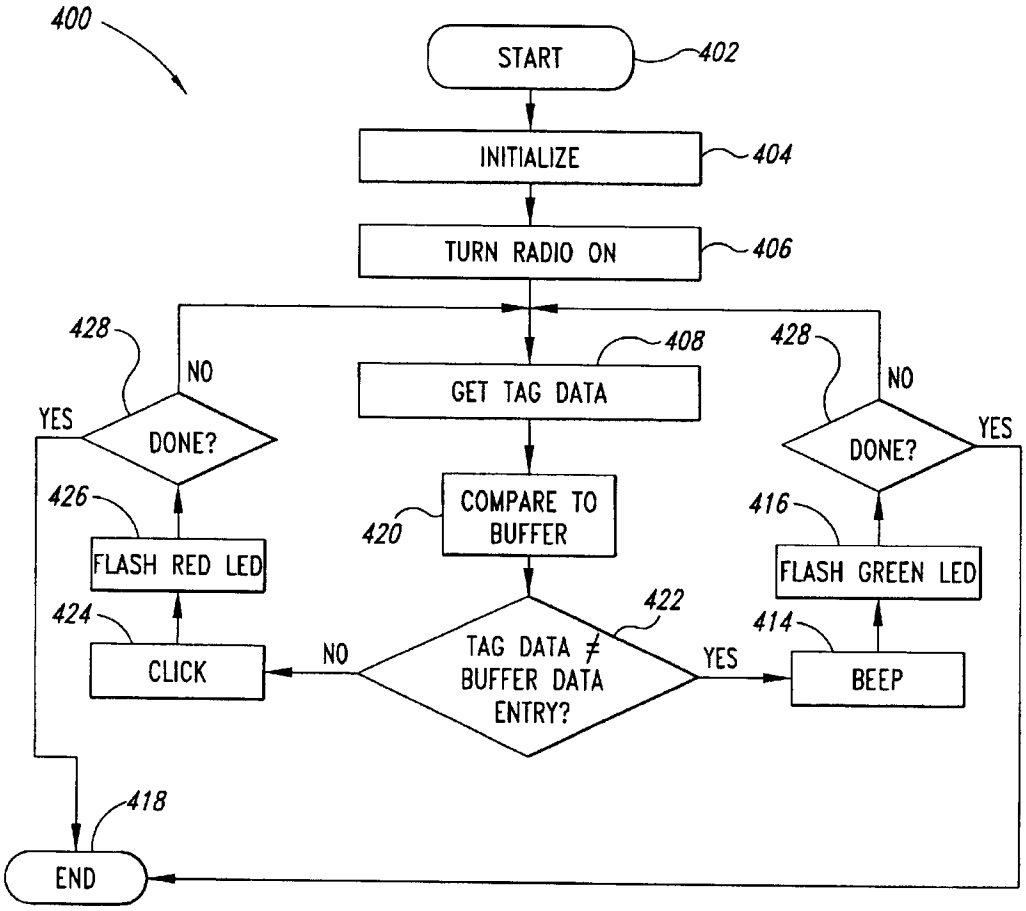

400
START
402
INITIALIZE
404
TURN RADIO ON
406
GET TAG DATA
408
COMPARE TO BUFFER
420
TAG DATA ≠ BUFFER DATA ENTRY?
422
NO
YES
CLICK
424
FLASH RED LED
426
DONE?
428
NO
YES
BEEP
414
FLASH GREEN LED
416
DONE?
428
NO
YES
END
418

Fig. 11

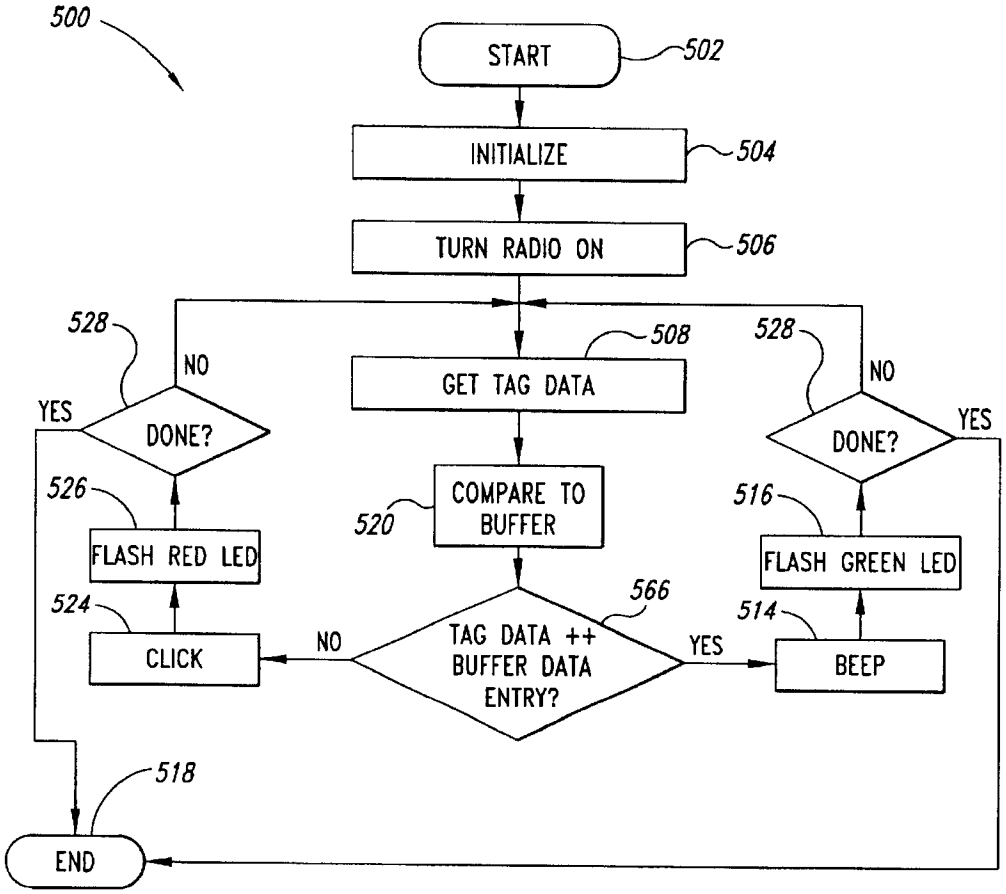

500
START
502
INITIALIZE
504
TURN RADIO ON
506
528
NO
YES
DONE?
526
FLASH RED LED
524
CLICK
508
GET TAG DATA
520
COMPARE TO BUFFER
566
TAG DATA ++ BUFFER DATA ENTRY?
NO
YES
528
NO
YES
DONE?
516
FLASH GREEN LED
514
BEEP
518
END

Fig. 12

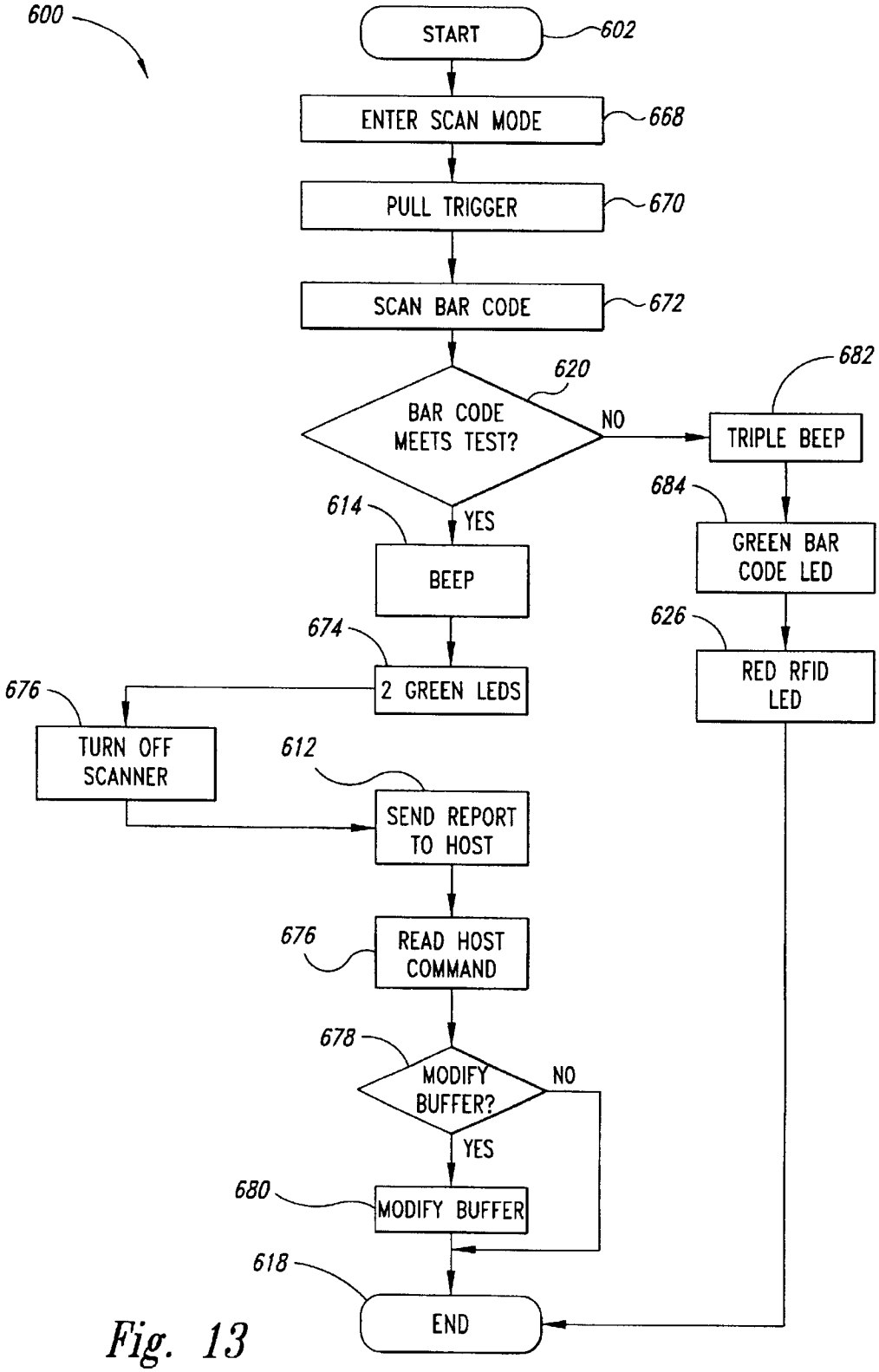

600
START
602
ENTER SCAN MODE
668
PULL TRIGGER
670
SCAN BAR CODE
672
620
BAR CODE MEETS TEST?
NO
682
TRIPLE BEEP
684
GREEN BAR CODE LED
626
RED RFID LED
614
YES
BEEP
674
2 GREEN LEDS
676
TURN OFF SCANNER
612
SEND REPORT TO HOST
676
READ HOST COMMAND
678
MODIFY BUFFER?
NO
YES
680
MODIFY BUFFER
618
END

Fig. 13

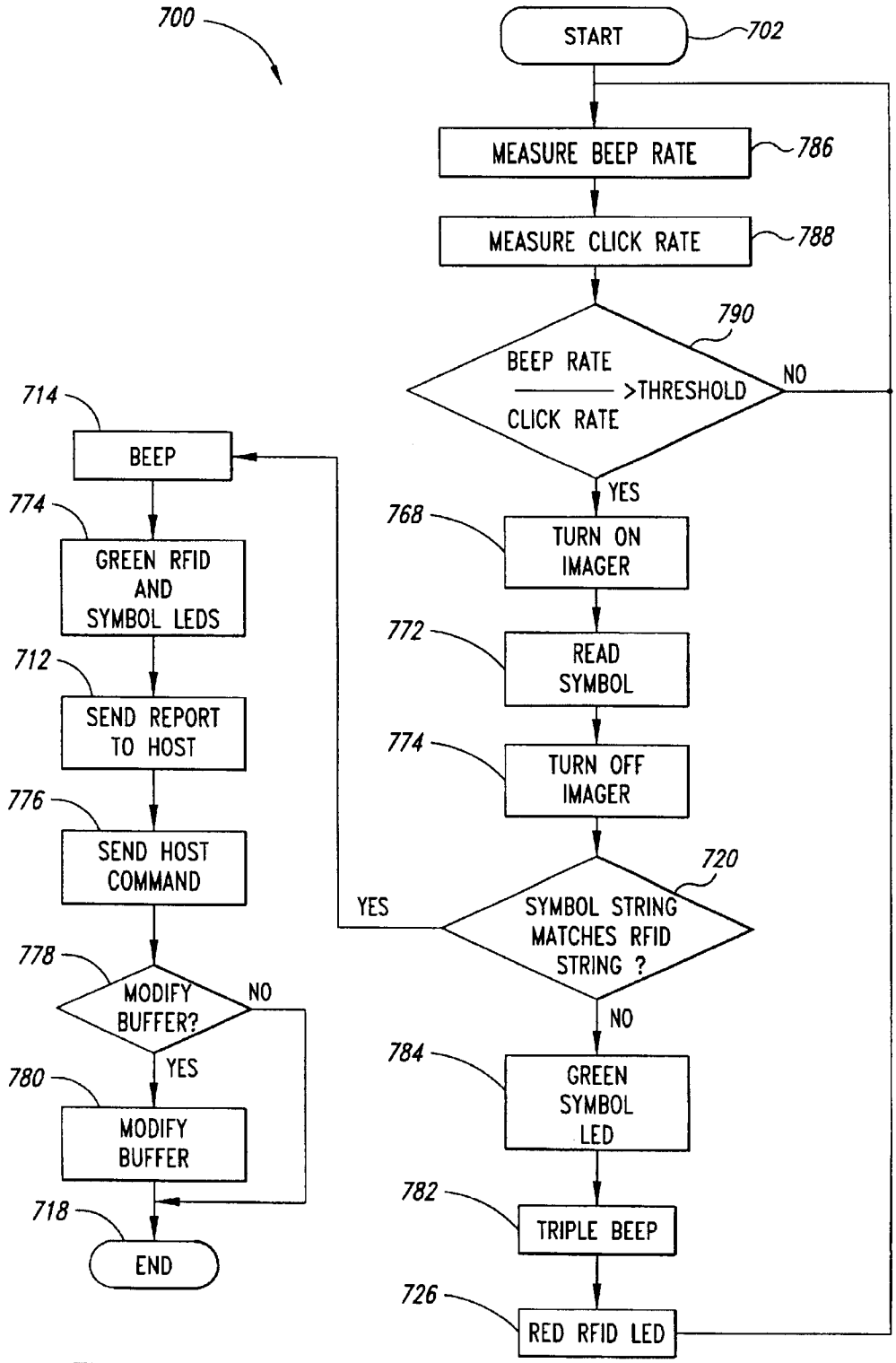

700
START
702
MEASURE BEEP RATE
786
MEASURE CLICK RATE
788
790
BEEP RATE / CLICK RATE >THRESHOLD
NO
YES
714
BEEP
774
GREEN RFID AND SYMBOL LEDS
712
SEND REPORT TO HOST
776
SEND HOST COMMAND
778
MODIFY BUFFER?
NO
YES
780
MODIFY BUFFER
718
END
768
TURN ON IMAGER
772
READ SYMBOL
774
TURN OFF IMAGER
720
SYMBOL STRING MATCHES RFID STRING ?
YES
NO
784
GREEN SYMBOL LED
782
TRIPLE BEEP
726
RED RFID LED

Fig. 14

METHOD AND APPARATUS TO PERFORM A PREDEFINED SEARCH ON DATA CARRIERS, SUCH AS RFID TAGS

TECHNICAL FIELD

This application relates to methods and apparatus for reading data carriers such as machine-readable symbols (e.g., barcode symbols, area and/or matrix code symbols) and wireless memory devices (e.g., RFID tags).

BACKGROUND OF THE INVENTION

A variety of methods exist for tracking and providing information about items. For example, inventory items typically carry printed labels providing information such as serial numbers, price, weight, and size. Some labels include data carriers in the form of machine-readable symbols that can be selected from a variety of machine-readable symbologies, such as bar code, and/or area or matrix code symbologies. The amount of information that the symbols can contain is limited by the space constraints of the label. Updating the information in these machine-readable symbols typically requires the printing of a new label to replace the old label.

Data carriers such as memory devices provide an alternative method for tracking and providing information about items. Memory devices permit the linking of large amounts of data with an object or item. Memory devices typically include a memory and logic in the form of an integrated circuit ("IC") and means for transmitting data to and/or from the device. For example, a radio frequency identification ("RFID") tag typically includes a memory for storing data, an antenna, an RF transmitter, and/or an RF receiver to transmit data, and logic for controlling the various components of the memory device. RFID tags are generally formed on a substrate and can include, for example, analog RF circuits and digital logic and memory circuits. The RFID tags can also include a number of discrete components, such as capacitors, transistors, and diodes.

RFID tags can be passive, active or hybrid devices. Active devices are self-powered, by a battery for example. Passive devices do not contain a discrete power source, but derive their energy from an RF signal used to interrogate the RFID tag. Passive RFID tags usually include an analog circuit that detects and decodes the interrogating RF signal and that provides power from the RF field to a digital circuit in the tag. The digital circuit generally executes all of the data functions of the RFID tag, such as retrieving stored data from memory and causing the analog circuit to modulate the RF signal to transmit the retrieved data. In addition to retrieving and transmitting data previously stored in the memory, the RFID tag can permit new or additional information to be stored in the RFID tag's memory, or can permit the RFID tag to manipulate data or perform some additional functions. RFID tags are available from a number of manufacturers, including Texas Instruments, Dallas, Tex., and Omron of Japan.

Another form of memory device is an optical tag. Optical tags are similar in many respects to RFID tags, but rely on an optical signal to transmit data to and/or from the tag.

Additionally, touch memory data carriers are available, for example touch memory devices from Dallas Semiconductor of Dallas, Tex. Touch memory devices are similar to RFID tags but require physical contact with to store and retrieve data.

A user typically secures a data carrier to an item, such as a good, product, or container by way of a pressure sensitive adhesive. The data carrier often encodes information specifically relating to the item such as identifying or destination information. An individual, such as a checkout or inventory clerk, can retrieve data about any given item, for example, by scanning the machine-readable symbol or interrogating the RF tag, optical tag, or touch memory device. Access to the data can be useful at the point of sale, during inventory, during transportation, or at other points in the manufacture, distribution, sale, or use of the tagged item.

Relatively high cost is one of the drawbacks of memory devices, thus, many applications rely on the less expensive printed machine-readable symbols. Another significant drawback is the difficulty of identifying a particular memory device from a group of memory devices. It is particularly difficult to associate the information read from the RFID tag with a physical item or container. The ability to read data from different types of data carriers, for example machine-readable symbols and RFID tags, and/or to associate and manipulate such data can provide numerous benefits in the automatic data collection ("ADC") industry.

SUMMARY OF THE INVENTION

In one aspect a data carrier reader includes an RFID tag reading section and a machine-readable symbol reading section, which can contain some common components. The reader is operable in an RFID tag reading mode and/or a symbol reading mode. The reader provides a consistent and intuitive user interface within, and between, the operating modes. The user interface can include visual, aural and tactile indicators. The visual indicators can include a pattern displayed by indicators on the reader, or projected onto or near the data carrier.

In another aspect, a data carrier reader is capable of executing a number of different reading methods. A method for reading single RFID tags can store read data to a buffer for eventual transmission to a host, and can suppress redundant data. Another method identifies all RFID tags having a characteristic data string that appears on a list. In contrast, another method identifies any RFID tags having a characteristic data string that does not appear on the list. Still another method associates data read from an RFID tag with a particular object or item using a data coded in a machine-readable symbol. In a further method, the machine-readable symbol is automatically read when the RFID tag is within a predetermined proximity of the reader. In each method, a consistent and intuitive output can be provided to the user to identify the successful and unsuccessful operations such as reading an RFID tag or machine-readable symbol.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, various elements may be arbitrarily enlarged and positioned to improve drawing legibility.

FIG. **1** is a partial block diagram, partial front elevational view of a facility including a data carrier reader reading data carriers carried by a number of items, the reader communicate with a host through an interface.

FIG. **2** is a functional block diagram of the reader according to one embodiment of the invention.

FIG. **3** is a top plan view of the reader of FIG. **2**.

FIG. **4** is a partial top plan view of an alternative set of visual indicators for the reader of FIG. **2**.

FIGS. **5A–5C** together form a chart of selected input and output signals for operating the reader of FIG. **2** and the visual indicators of FIG. **4**.

FIG. **6** is a top plan view of a graphic display of the reader of FIG. **3**.

FIG. **7** is a top plan view of an alpha-numeric display of the reader of FIG. **3**.

FIG. **8** is a flowchart showing a method of reading single RFID tags.

FIG. **9** is a flowchart showing a method of determining when a reader is finished reading RFID tags.

FIG. **10** is a flowchart showing a method of reading multiple RFID tags.

FIG. **11** is a flowchart showing a method of performing an inclusive search of RFID tags.

FIG. **12** is a flowchart showing a method of performing an exclusive search of RFID tags.

FIG. **13** is a flowchart showing a method of associating data from an RFID tag with an item using a machine-readable symbol.

FIG. **14** is a flowchart showing a method of automatically imaging a machine-readable symbol based on proximity to an RFID tag to associate data from an RFID tag with an item using the machine-readable symbol.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, certain specific details are set forth in order to provide a thorough understanding of various embodiments of the invention. However, one skilled in the art will understand that the invention may be practiced without these details. In other instances, well-known structures associated with RFID tags, RFID tag readers, one- and two-dimensional symbologies, symbol readers, microprocessors and communication networks have not been shown or described in detail to avoid unnecessarily obscuring descriptions of the embodiments of the invention.

The headings provided herein are for convenience only and do not interpret the scope or meaning of the claimed invention.

Data Carrier Reader

FIG. **1** shows a data carrier reader **10** reading one or more of a number of data carriers, such as the RFID tags **12** on the containers or items **14**. The reader **10** includes a head **16**, a handle **18** and a trigger **20**. An interface **22** can couple the reader **10** to a host **23**, such as a centralized computer, as described in detail below.

The tags **12** can take the form of an RFID tag **12A** that carries a machine-readable symbol **24A** on a visible surface of the tag. Alternatively, the tags **12** can take the form of a separate RFID tag **12B** and machine-readable symbol **24B**. The separate RFID tag **12B** and machine-readable symbol **24B** can be physically associated, for example, securing each to the same physical object, such as the item **14**. The RFID tag **12A**, **12B** and machine-readable symbol **24A**, **24B** can contain logically associated information, for example information related to the item **14** to which the tags **12** are secured, such as identifying and/or shipping information.

As shown in FIG. **2**, the reader **10** contains an RFID tag reading section **30**, a symbol reading section **32**, a user input section **34**, a user output section **36**, and a communications section **38** all coupled by a bus **40**. The bus **40** provides data, commands and/or power to the various sections **30–38**. The reader **10** can include an internal power source such as a rechargeable battery (not shown) or can receive power from an external power source such as a wall outlet by way of an electrical cord (not shown). Each of these sections **30–38** will be described individually below, although in the illustrated embodiment some of these sections share common components.

RFID Tag Reading Section

FIG. **2** shows the RFID tag reading section **30** of the data carrier reader **10** including an antenna **42** coupled to a radio **44**. The radio **44** is coupled via the bus **40** to a microprocessor **46** and a random access memory ("RAM") **48**. The RAM **48** can include a characteristic data string buffer **49** to temporarily store characteristic data strings, as will be explained in detail below. Alternatively, the reader **10** can include a discrete characteristic data string buffer (not shown). While FIG. **2** shows a single microprocessor **46**, the data carrier reader **10** may include separate dedicated processors for each of the RFID tag and symbol reading sections **30**, **32**.

While a dipole antenna **42** is shown, the data carrier reader **10** can employ other antenna designs. Of course, the antenna can be selected to achieve a particular focus, for example, a highly directional antenna can enhance the ability of the reader **10** to select a single RFID tag **12** out of a group of RFID tags. The radio **44** can take the form of a transceiver capable of transmitting and receiving at one or more of the frequencies commonly associated with RFID tags **12** (e.g., 350 kilohertz, 400 kilohertz, 900 kilohertz). While these frequencies typically fall within the radio frequency range of the electromagnetic spectrum, the radio **44** can successfully employ frequencies in other portions of the spectrum. Antenna design and radios are generally discussed in *The ARRL Handbook for Radio Amateurs*, 76th Ed., American Radio Relay League, Newington, Conn., U.S.A. (1999) (ISBN: 0-87259-181-6), and commonly assigned patent application U.S. Ser. No. 09/280,287, filed Mar. 29, 1999, entitled ANTENNA STRUCTURES FOR WIRELESS COMMUNICATIONS DEVICE, SUCH AS RFID TAG (Atty. Docket No. 480062.648).

A read only memory ("ROM") **50** stores instructions for execution by the microprocessor **46** to operate the radio **44**. As used in this herein, ROM includes any non-volatile memory, including erasable memories such as EEPROMs. The programmed microprocessor **46** can control the radio **44** to emit an interrogation signal, including any required polling codes or encryption, and to receive a return signal from an RFID tag **12A**, **12B**. The programmed microprocessor **46**, RAM **48**, radio **44** and antenna **42** thus form the RFID reading section **30**.

Symbol Reading Section

FIG. **2** also shows the symbol reading section **32** of the data carrier reader **10** including an image sensor **52** and an illumination source, such as the laser **53**. The image sensor **52** can take the form of a one- or two-dimensional charge coupled device ("CCD") array. Alternatively, the reader **10** can employ other known imaging devices, for example laser scanners or Vidicons. In certain embodiments, the data carrier reader **10** can omit the illumination source, for example where the image sensor **52** is a two-dimensional CCD array operable with ambient light. Alternatively, the data carrier reader **10** can rely on other illumination sources, such as light emitting diodes ("LEDs") or a strobe light, that can be positioned to illuminate a desired one of the machine-readable symbols **24A**, **24B**. The reader **10** can employ suitable optics such as lens and mirrors (not shown) for directing light reflected from the machine-readable symbol **24A**, **24B** to the image sensor **52**.

The reader **10** includes an analog-to-digital ("A/D") converter **54**, to transform the analog electrical signals from the image sensor **52** into digital signals for use by the microprocessor **46**. The bus **40** couples the image data from the A/D converter **54** to the microprocessor **46** and the RAM **48**. A portion of the RAM **48** can form an image buffer **56** for

temporarily storing data, such as a captured image data from the image sensor **52**. The ROM **50** contains instructions for the microprocessor **46**, that permit the microprocessor **46** to control the image sensor **52** to capture image data and to decode and/or manipulate the captured image data. The programmed microprocessor **46**, RAM **48**, image sensor **52**, and A/D converter **54**, thus form the symbol reading section **32**.

Symbol reading and decoding technology is well-known in the art and will not be discussed in further detail. Many alternatives for image sensors, symbol decoders, and optical elements that can be used in the reader **10** are taught in the book, *The Bar Code Book*, Third Edition, by Roger C. Palmer, Helmers Publishing, Inc., Peterborough, N.H., U.S.A. (1995) (ISBN 0-911261-09-5).

Communications Section

The communications section **38** includes a communications buffer **47** and a communications port **49**. The communications buffer **47** can temporarily store incoming and outgoing data and/or commands where the communications speed of the reader **10** does not match the communications speed of some external device, such as the interface **22** (FIG. **1**). The communications port **49** provides communications between the reader and external devices. While shown as a hardwire connection to the interface **22** (FIG. **1**), the communications port can be a wireless interface, and can even employ the antenna **42** and radio **44** of the RFID tag reading section **30**. Additionally, the reader **10** can include the interface **22** as an integral part of the reader **10**.

The interface **22** (FIG. **1**) can provide communications over a communications network **68** to the host **23**, allowing transmissions of data and/or commands between the reader **10** and the host **23**. The communications network **68** can take the form of a wired network, for example a local area network ("LAN") (e.g., Ethernet, Token Ring), a wide area network ("WAN"), the Internet, or the World Wide Web ("WWW"). Alternatively or additionally, the communications network **68** can be a wireless network, for example, employing infrared ("IR"), satellite, and/or radio frequency ("RF") communications.

The host **23** can receive from each of a number of the readers **10**, data collected from the RFID tags **12** and machine-readable symbols **24**. The host **23** can use the data with a database, and can automatically manipulate the data, for example to automatically performing inventory or to track shipments.

The host **23** can provide data and commands to each of a number of the readers **10**. For example, the host can share data between the readers **10**, such as providing a list of either located or missing identifiers, as will be discussed in more detail below in reference to inclusive and exclusive searches. The host **23** can provide a command to toggle the reader **10** between an RFID tag reading mode and a symbol reading mode, which is described below in further detail. Thus, the host **23** can command, coordinate and share data between a number of readers **10**. Commonly assigned patent application U.S. patent application Ser. No. 09/401,066, filed Sep. 22, 1999, entitled, "SYSTEM AND METHOD FOR AUTOMATICALLY CONTROLLING OR CONFIGURING A DEVICE, SUCH AS AN RFID READER" (Atty. Docket No. 480062.672) contains teachings that can be used to automatically control or configure the reader **10**.

User Input Section

The user input section **34** includes the trigger **20**, the mode switch **34**, and can include a user input device **58**. The bus **40** couples the mode switch **34** to the microprocessor **46**. In response to selection of the mode switch **34**, the microprocessor **46** switches between the symbol reading mode and the RFID tag reading mode, for example by toggling between the two operating modes. The reader **10** can employ additional operating modes, or switching positions as desired, for example a switch position that places the reader **10** in an OFF state or a WAIT state to conserve energy.

In the symbol reading mode, the microprocessor **46** operates the image sensor **52** to image one of the machine-readable symbols **24A**, **24B**. The microprocessor **46** decodes the imaged symbol to retrieve the data encoded in the machine-readable symbol **24A**, **24B**, such as a respective identifier. In the RFID tag reading mode, the microprocessor **46** operates the radio **44** to emit an interrogation signal and to receive a response from one or more of the RFID tags **12A**, **12B** to the interrogation signal. The microprocessor **46** decodes the response signal to retrieve the data encoded in the RFID tag **12A**, **12B**, such as a respective identifier.

The mode switch **34** can be a membrane switch, mounted to the exterior of the reader **10** for easy selection by the user. The mode switch **34** can additionally, or alternatively, be implemented in the software to supplement or replace the user selectable mode switch on the exterior of the reader **10**. The software implemented switch is particularly useful where the host **23** (FIG. **1**) controls the operating mode of the reader **10**. Alternatively, the mode switch **34** can be implemented as an icon on a touch sensitive display **74**. In further alternatives, the trigger **20** can function as the mode switch **37**. In one instance, the number of successive trigger pulls or activations can determine the operating mode. For example, two successive trigger pulls can select the symbol mode, while three successive trigger pulls selects the RFID mode; or a single trigger pull can cause the reader **10** to read a symbol while a double trigger pull toggles between the symbol and RFID modes. Alternatively, the duration of trigger activation can determine the operating mode. For example, a trigger pull of under 0.5 seconds can select the symbol mode, while a trigger pull of longer than 0.5 seconds can select the RFID mode; or a trigger pull of under 0.5 seconds can cause the reader **10** to read a symbol while a trigger pull of over 0.5 seconds toggles the reader between the symbol and RFID modes. Additionally, or alternatively, the mode switch can be context sensitive, switching modes based on data read from a previously read data carrier **12A**, **12B**, **24A**, **24B**. For example, a previously read RFID tag **12A** can indicate the existence of a symbol **24A**. In response, the data carrier reader **10** can automatically switch into symbol mode and read the symbol **24A** associated with the RFID tag **12A**.

The bus **40** also couples the trigger **20** to the microprocessor **46**. In response to activation of the trigger **20**, the microprocessor **46** can cause the image sensor **52** to image one of the machine-readable symbols **24A**, **24B** when the reader **10** is operating in the symbol reading mode. In at least one embodiment, the microprocessor **46** can also cause the radio **44** and antenna **42** to emit an interrogation signal in response to the activation of the trigger **20** while in the reader **10** is operating in the RFID tag reading mode.

The user input device **58** can take the form of a keypad **60** (FIG. **3**), mouse, touch screen and/or other user operable device to input information and/or commands to the reader **10**. The bus **40** couples the user input device **58** to the microprocessor **46**, to allow the user to enter data and commands.

User Output Section

The user output section **36** includes human-perceptible visual and audio indicators **62**, **64** respectively. The bus **40** couples the visual and audio indicators **62**, **64** to the micro-

processor **46** for control thereby. The visual indicators **62** can take a variety of forms, for example: light emitting diodes ("LEDs"); a graphic display such as a liquid crystal display ("LCD"), and/or an alpha-numeric display such as a 7-segment display. The audio indicator **64** can take the form of one or more dynamic, electrostatic or piezo-electric speakers **66**. The speaker **66** is operable to produce a variety of sounds (e.g., Clicks and Beeps), and/or frequencies (e.g., tones), and to operate at different volumes. The reader **10** can also include tactile indicators such as a vibrating member. The specific operation of the user output section **36** is discussed in more detail below.

FIG. **3** shows a portion of the user interface located on the head **16** of the reader **10**. The user interface includes the elements of the user input section **34**, such as the trigger **20**, the mode switch **34** and the keypad **60**. The user interface also includes the elements of the user output section **36** including the visual indicators **63** and the speaker **66**. In particular, the visual indicators **62** in the illustrated embodiment include a set of RFID related LEDs **70**, a set of machine-readable symbol related LEDs **72**, and a display **74**.

The data carrier reader **10** can additionally, or alternatively, employ the laser **53** as the visual indicator. The laser can be successively pulsed or flashed according to a set of predefined human-recognizable temporal patterns to provide information to the user, such as user indications corresponding to the various reader operations and/or the responses from the date carriers **12A, 12B, 24A, 24B**. Employing the laser **53** as a portion of the user interface provides a number of distinct benefits. For example, operating the laser **53** to provide human-recognizable patterns can eliminate the need for other visual indicators **62**. The data carrier reader **10** can employ multiple illumination sources such as lasers **53** or LEDs of different colors, or an illumination source capable of producing a number of different colors to provide the appropriate user indications, as set out in FIGS. **5A–5C**. As discussed in detail below, the human-recognizable patterns can take the form of a predefined sequence of laser flashes of one or more colors, separated by time (i.e., temporal pattern).

The visual and audio indicators **62, 64** are configured to provide an intuitive user interface consistent across the RFID tag and symbol reading modes. For example, the RFID tag related and symbol related LED sets **70, 72** each contain green **76, 78**, yellow **80, 82** and red **84, 86** LEDs, in an order or pattern that is consistent between the sets. The particular LED **76–86**, as well as the number and/or pattern of flashes, is set such that the same color LEDs flash the same pattern for analogous RF tag reading and symbol reading activities. For example, the yellow LED **80** in the RFID tag related set **70** flashes during the reading of one of the RFID tags **12A, 12B** (FIG. **1**), while the yellow LED **82** in the machine-readable symbol related set **72** flashes during the reading of one of the machine-readable symbols **24A, 24B** (FIG. **1**). The reader **10** responds to a successful read of the RFID tag **12A, 12B** or machine-readable symbol **24A, 24B** by illuminating the corresponding green LED **76, 78**, respectively, for a set period of time such as 5 seconds. The red LEDs **84, 86** can indicate unsuccessful or incomplete operations. The user receives visual feedback, where the color, position and sequence of the visual indicators **62** is consistent within, and across the RFID tag and symbol operating modes. Consistent feedback can reduce training time and costs, and can lead to more efficient operation of the reader **10**.

Similar to the visual indicators **62**, the speaker **66** provides consistent feedback within and across the operating modes. In the illustrated embodiment, the speaker **66** emits a "beep" or a "click" sound, although the speaker **66** can emit different and/or additional sounds. The speaker **66** can emit, for example, a single beep each time either an RFID tag **12A, 12B** or a machine-readable symbol **24A, 24B** is successfully read. When searching a field of RFID tags **12A, 12B** for one or more particular tags, the speaker **66** can emit a click for each non-match and a beep for each match.

The user interface can also include an ON/OFF indicator **97**, and/or a Low Power indicator **99** to identify the operating condition of the reader **10**.

FIG. **4** shows an alternative set of visual indicators for the reader **10**. his alternative embodiment, and those alternative embodiments and other alternatives described herein, are substantially similar to previously described embodiments, and common acts and structures are identified by the same reference numbers. Only significant differences in operation and structure are described in detail below.

The reader **10** of FIG. **4** employs only three LEDs to simplify switching while providing the human-perceptible visual indications. A two state LED serves as the machine-readable symbol related indicator **87**. The machine-readable symbol indicator **87** produces no light in an OFF state and a Green light in an ON state. A three state LED serves as the RFID related indicator **89**. The RFID related indicator **89** produces a Green light in first ON state, a Yellow light in second ON state, and NO light in an OFF state. A two state LED serves as the ON/OFF indicator **97**. The ON/OFF indicator produces a Yellow light, or No light. The ON/OFF indicator is proximate the machine-readable symbol related and RFID related indicators **87, 89**. In FIG. **4**, the mode switch **34** takes the form of a toggle or slider switch, having a neutral position (center), a symbol mode position (left of center) and an RFID mode position (right of center). The positions are consistent with the corresponding visual indicators **87, 89**, respectively.

FIGS. **5A–C** describe a variety of input and outputs signals for the reader **10**, and particularly for the audio indicator **64** and laser **53** of FIG. **2**, and for the visual indicators **87, 89, 97** of FIG. **4**. While the table is self-explanatory, a brief description of the columns follows. Column **31** defines a reader status or error conditions corresponding to reader activities. Column **33** describes the operation of the visual indicators **87, 89, 97** of FIG. **4**, in response to the various reader status or errors conditions. Similarly, column **35** describes the operation of the audio indicator **64** in response to the various reader status or error conditions **33**. Column **37** describes the operation of the laser to produce the desired human-recognizable patterns corresponding to the various reader status or errors conditions **31**. Column **39** describes messages for display on the display **74** corresponding to the various reader status or errors conditions **31**. Column **41** describes PDT/Host messages corresponding to the various reader status or errors conditions **31**. Column **43** describes data and/or error codes sent to the host **33**, corresponding the various reader status or errors conditions **31**. As discussed above, these user indications provide a consistent interface for the user within and across the operating modes, permitting the user to efficiently operate the reader **10**.

The display **74** can additionally, or alternatively, provide the user other visual indications. For example, a graphical display **88** (FIG. **6**), can employ a first set of icons **90** to indicate RFID tag activities and a second set of icons **92** to indicate symbol reading activities. (Note, typically only a single icon will be displayed at a time, although multiple icons are shown in FIG. **6** for the convenience of this

description.) For example, screen icons **81**, **83** and **85** can represent RFID reading, successful reading of the RFID tag **12A**, **12B**, and unsuccessful reading of RFID tag **12A**, **12B**, respectively. Similarly, screen icons **91**, **93** and **95** can represent machine-readable symbol reading, successful reading of the machine-readable symbol **24A**, **24B**, and unsuccessful reading of the machine-readable symbol **24A**, **24B**, respectively.

Similarly, an alpha-numeric display **94** (FIG. **7**) can employ a first set of words **96** to indicate RFID tag activities and a second set of words **98** to indicate symbol reading activities. (Again, typically only a single word will be displayed at a time, although multiple are shown in FIG. **7** for the convenience of this description.) The display **94** is self-explanatory and in the interest of brevity will not be further described. Other visual indications, as well as audio and tactile indications are of course possible.

Selected Methods of Operation

Different methods of operating the reader **10** or a reader having similar capabilities are disclosed below. As set out in the below methods, the intuitive and consistent operation of the user interface within and across operating modes can provide numerous benefits. While several methods are set out for illustration, other methods employing similar techniques are within the scope of the invention. Also, the following descriptions employ certain descriptions of user outputs (e.g., Beep, Click, Red LED, Yellow LED, and Green LED) for convenience of description. Those skilled in the art will appreciate that other sounds, colors, visual, tactile indications, and/or other human-perceptible indications could be used.

Single Tag Read Mode

FIG. **8** shows a method **100** of reading RFID tags **12A–12B** (FIG. **1**) employing the reader **10** (FIGS. **1–3**). Turning on the reader **10**, or switching into the RFID tag reading mode, can automatically cause the microprocessor **46** to start the method **100** in step **102**. Alternatively, or additionally, the user can cause the microprocessor **46** to start the RFID tag reading method **100** by selecting an appropriate key from the keypad **60** or icon from the display **74**. Upon starting in step **102**, the microprocessor **46** can perform an initialization process, for example loading appropriate operating instructions from the ROM **50** to the RAM **48**, initializing the characteristic data string buffer **49** and/or performing a series of systems checks on the various component and subsystems of the reader **10**, as set out in step **104**.

Under the instructions loaded in the RAM **48**, the microprocessor **46** activates the radio **44** in step **106**. In step **108**, the radio **44** receives data from the RFID tags **12A**, **12B**. The radio **44** can emit an interrogation signal to cause the RFID tags **12A**, **12B** to respond, or, the radio **44** can simply receive signals from RFID tags **12A**, **12B** that emit signals without interrogating the RFID tags. A variety of passive, active and hybrid RFID tags **12A**, **12B** are known in the art and will not be discussed in further detail. A discussion of RFID tags can be found in commonly assigned patent applications: U.S. Ser. No. 09/173,539, filed Oct. 15, 1998, entitled WIRELESS MEMORY DEVICE AND METHOD OF MANUFACTURE (Atty. Docket No. 480062.630); U.S. Ser. No. 09/164,203, filed Sept. 30, 1998, entitled MEMORY TAG AND METHOD OF MANUFACTURE (Atty. Docket No. 480062.632); U.S. Ser. No. 09/173,137, filed Oct. 15, 1998, entitled RF TAG HAVING STRAIN RELIEVED STIFF SUBSTRATE AND HYDROSTATIC PROTECTION FOR A CHIP MOUNTED THERETO (Atty. Docket No. 480062.635); and U.S. Ser. No. 09/164,200, filed Sept. 30, 1998, entitled CHIP PLACEMENT ON SMART LABELS (Atty. Docket No. 480062.642).

In step **110**, the microprocessor **46** determines whether duplicate tag data should be suppressed. If suppressed, previously read or acquired data will not be stored or reported a second time. Suppression can be a user selection, or can be a selection transferred from the host **23**, or can be preset, for example by the reader manufacturer or owner. If suppression is not active, the reader **10**, in step **112**, automatically transmits the read data, for example to the host **23**, and provides an indication to the user that the data has been received and transmitted. To provide the indication, the reader **10** activates the speaker **66** to emit a single "beep" and activates the Green RFID related LED **76** for a short time, in steps **114**, **116**, respectively. Control passes to an end of the routine **100**, in step **118**.

If suppression is active, the microprocessor **46**, compares a characteristic data string from the received data to other characteristic data strings stored in the characteristic data string buffer **49**, in step **120**. The characteristic data string can be any string of characters stored in the RFID tags **12A**, **12B** that permit the reader **10** to determine whether a particular RFID tag **12A**, **12B** has been read more than once. For example, the characteristic data string can be a unique identifier programmed into each of the RFID tags **12A**, **12B**. Alternatively, the characteristic data string can be the entire set of data stored in the RFID tag **12A**, **12B**, or can be any subset or field of data recognizable by position, offset, delimiter or other such field identifier. The microprocessor **46** branches at step **122** based on the determination of whether the received characteristic data string corresponds, or matches, any of the stored data strings.

If the received characteristic data string corresponds to, or matches, any of the stored characteristic data strings, the reader **10** provides an indication that the RFID tag **12A**, **12B** has been read again, activating the speaker **66** to emit a single "click" and activating or "flashing" the Red RFID related LED **84** in steps **124**, **126**, respectively. The microprocessor **46** determines in step **128**, if the reader **10** is finished reading RFID tags **12A**, **12B**, as described in detail below.

If the received characteristic data string does not correspond to, or match any of the stored data strings, the microprocessor **46** updates the characteristic data string buffer **49** containing the read characteristic data strings, for example storing the newly received characteristic data string to the buffer **49** in step **130**. The reader **10** can automatically transmit the read data in step **132**, for example to the host **23** (FIG. **1**). The reader **10** also provides an indication that a new RFID tag **12A**, **12B** has been read (e.g., read for the first time since the buffer **49** was initialized), activating the speaker **66** to emit a "beep" in step **134** and activating the Green RFID related LED **76** in step **136**. Control passes to the end of the routine **100** in step **118**.

FIG. **9** is a flowchart of a method **200** of determining when a reader **10** is finished reading. The microprocessor **46** can execute this method **200** in place of each step labeled "DONE" in the various other methods, such as at step **128** of FIG. **8** (discussed above), or in the other Figures (discussed below). As set out in the Figures, the method **200**, starting at step **202**, acts as a function or subroutine, returning a Boolean value (e.g., TRUE/FALSE, YES/NO, or DONE/NOT DONE conditions). While the method **200** could be implemented as an integral part of the other methods discussed herein, it is set out separately for ease of discussion.

At step **240**, the microprocessor **46** determines whether the trigger **20** has been released. A trigger release indicates

that the user is finished reading. If the trigger **20** has been released, the microprocessor **46** sets the Boolean value to "DONE" at step **242**, and passes control to an end of the routine **200** at step **218**, returning the appropriate Boolean value. For example, when returning to the method **100** (FIG. **8**), the condition "DONE" can cause the reader **10** to stop interrogating RFID tags **12A**, **12B**.

If the trigger **20** has not been released, the microprocessor **46** in step **244** determines whether a timeout condition has been exceeded. For example, the reader **10** can assume that all RFID tags **12A**, **12B** have been read if a new (e.g., not previously read) tag is not found after some length of time or some number of consecutive repeatedly read RFID tags **12A**, **12B**. While the length of time or number of repeated reads can be preset, the length or number of repeats can also be determined during the reading, for example as a function of RFID tag density (e.g. number of RFID tags per unit time). The microprocessor **46** can rely on an internal clock or a separate clock circuit (not shown) in measuring the timeout period. Employing RFID tag density to calculate the stopping condition "on the fly" reduces the likelihood of ending a search prematurely .

If the timeout condition is exceeded, the reader **10** considers reading to be finished, sets the Boolean value to "DONE" at step **242**, and passes control to the end of the method **200** at step **218**, producing the appropriate Boolean value for determining the next operation, such as turning the radio OFF. If the timeout condition is not exceeded, the microprocessor **46** determines whether a stop command has been received from the host **23** in step **246**. If a stop command has been received, the Boolean value is again set to "DONE" at step **242**, and control passes to the end of the method **200** at step **218**. If a stop command has not been received from the host **23**, the microprocessor **46** at step **248**, determines whether all RFID tags **12A**, **12B** have been read. If all RFID tags **12A**, **12B** have been read, the Boolean value is set to "DONE" at step **242** and control passes to the end of the method **200** at step **218**, returning the appropriate response. If all RFID tags **12A**, **12B** have not been read, the Boolean value is set to "NOT DONE" at step **250** and control passes to the end **218**, thereby returning the appropriate Boolean value.

Multi Tag Read/Write Modes

FIG. **10**, shows an additional, or alternative embodiment of operating under the present invention. Similar steps in the methods are assigned reference numerals that have the two least significant digits in common (e.g., the "Start" step is respectively numbered: **102**, **202**, **302**, . . . , **702** in FIGS. **6–12**, respectively).

FIG. **10** shows a method **300** of reading multiple RFID tags **12A**, **12B** (FIG. **1**) employing the reader **10** (FIGS. **1–3**). In a similar fashion to the method **100**, the microprocessor **46** starts executing the method **300** at step **302**, initializing the reader **10** at step **304**, turning ON the radio **44** in step **306**, and receiving responses from the RFID tags **12A**, **12B** in step **308**. In step **320**, the microprocessor **46** compares a characteristic data string from the received data to other characteristic data strings stored in the characteristic data string buffer **49** to determine whether the reader **10** has read the particular RFID tag **12A**, **12B** before. The microprocessor **46** branches at step **322** based on the determination of whether the received characteristic data string corresponds, or matches, any of the stored data strings.

If the received characteristic data string corresponds to, or matches, any of the stored characteristic data strings, the microprocessor **46** adds the read characteristic data string to the characteristic data string buffer **49**, at step **330**. The reader **10** provides an indication that the read RFID tag **12A**, **12B** has been previously read, activating the speaker **66** to emit a single "click" and activating or "flashing" the Red RFID related LED **84** at steps **352** and **354**, respectively. In step **356**, the microprocessor **46** examines a counter ("Retry") to determine whether a maximum number of iterations has been exceeded without finding a "new" (e.g. not previously read) RFID tag **12A**, **12B**. If the number of iterations without encountering a new RFID tag **12A**, **12B** has been exceeded, control passes to an end of the method **300** at step **318**. If the number of iterations without encounter a new RFID tag **12A**, **12B** has not been exceeded, the microprocessor **46** increments the Retry counter in step **358**, and determines in step **328** whether the reader **10** is finished reading RFID tags **12A**, **12B**, as described in detail above with respect to method **200** (FIG. **9**). The microprocessor **46** returns to receiving RFID tag responses in step **308**, or passes control to the end of the method **300** at step **318** based on the Boolean value returned by the method **200** (FIG. **9**).

If the received characteristic data string does not correspond to, or match any of the stored data strings, the microprocessor **46** resets the Retry counter in step **360**, and adds the read characteristic data string to the characteristic data string buffer **49** in step **362**. The reader **10** in step **364**, automatically transmits the read data, for example to the host **23**. The reader **10** also provides an indication that a new RFID tag **12A**, **12B** has been read (e.g., read for the first time since the buffer **49** was initialized), activating the speaker **66** to emit a "beep" in step **314** and activating the Green RFID related LED **76** in step **316**. The microprocessor **46** determines in step **328** whether the reader **10** is finished reading RFID tags **12A**, **12B**, as described in detail above with respect to method **200** (FIG. **9**). The microprocessor **46** returns to receiving RFID tag responses in step **308** or passes control to the end of the method **300** in step **318** based on the condition returned by the method **200**.

Inclusive Search

The reader **10** can perform an "inclusive" search, such as finding all RFID tags **12A**, **12B** on a list of RFID tags **12A**, **12B**. FIG. **11** shows a method **400** for performing an inclusive search. The user can start the inclusive search **400** by, for example, selecting an appropriate key or icon as in step **402**. The microprocessor **46** performs an initialization at step **404**, for example loading a list of characteristic data strings for the RFID tags **12A**, **12B** to be located or identified into the characteristic data string buffer **49**. The list of characteristic data strings can, for example, be downloaded from the host **23** via interface **22**. The microprocessor **46** turns ON the radio **44** at step **406**.

In step **408**, the radio **44** interrogates the RFID tags **12A**, **12B** to receive response signals containing the respective characteristic data strings. Alternatively, the radio **44** can receive the response signals without interrogating if the RFID tags **12A**, **12B** are active and periodically transmit data without requiring initiation by an interrogation signal. In step **420**, the microprocessor **46** compares the received characteristic data string with the characteristic data strings stored in the characteristic data string buffer **49**. The microprocessor **46** branches at step **422**, based on the determination of whether the received characteristic data string corresponds, or matches, any of the stored data strings.

If the read characteristic data string corresponds to, or matches any of the stored characteristic data strings, then one of the RFID tags **12A**, **12B** has been found and the reader **10** reports such to the user and/or host **23**. The reader **10** provides the user indication by activating the speaker **66** to "beep" in step **414** and activating or "flashing" the Green

RFID related LED **76** in step **416**. If the read characteristic data string does not correspond to, or match any of the stored characteristic data strings, then one of the RFID tags **12A, 12B** has not been found, and the reader **10** reports such to the user, and/or host **23**. The reader **10** provides the user indication by activating the speaker **66** to "click" in step **424** and activating or "flashing" the Red RFID related LED **84** in step **426**.

After providing the user indications, the microprocessor determines whether the reader is finished reading, in step **428**. If the reading is finished, the returned Boolean value (i.e., DONE) causes control to pass to an end of the inclusive search routine **400** in step **418**. If the reading is not finished, the returned Boolean value (i.e., NOT DONE) causes the radio **22** to continue receiving response signals, passing control to step **418**.

Exclusive Search

The reader **10** can perform an "exclusive" search, such as finding any RFID tags **12A, 12B** not on a list of RFID tags **12A, 12B**. FIG. **12** shows a method **500** for performing an exclusive search. The user can start the exclusive search **500** at step **502** by, for example, selecting an appropriate key or icon. The microprocessor **46** performs an initialization at step **504**, for example loading a list of characteristic data strings for the RFID tags **12A, 12B** to be located. At step **506**, the microprocessor turns ON the radio **44**.

In step **508**, the radio interrogates the RFID tags **12A, 12B** to receive response signals containing the respective characteristic data strings. Alternatively, the radio can receive the response signals without interrogating if the RFID tags **12A, 12B** are active and periodically transmit without requiring an interrogation signal. In step **520**, the microprocessor **46** compares the received characteristic data string with the characteristic data strings stored in the characteristic data string buffer **49**. The microprocessor **46** branches at step **566**, based on the determination of whether the received characteristic data string does not correspond, or match, any of the stored data strings.

If the read characteristic data string does not correspond to, or match any of the stored characteristic data strings, then one of the RFID tags **12A, 12B** missing from the list has been found, and the reader **10** reports such to the user and/or host **23**. The reader **10** provides the user indication by activating the speaker **66** to "beep" in step **514**, and activating or "flashing" the Green RFID related LED **76** in step **516**. If the read characteristic data string corresponds to, or matches any of the stored characteristic data strings, then one of the RFID tags **12A, 12B** missing from the list has not been found, and the reader **10** reports such to the user, and/or host **23**. The reader **10** provides the user indication by activating the speaker **66** to "click" in step **524**, and activating or "flashing" the Red RFID related LED **84** in step **526**.

After providing the user indications, the microprocessor **46** determines whether the reader **10** is finished reading, in step **528**. If the reading is finished, the returned Boolean value (i.e., DONE) causes control to pass to an end of the exclusive search routine **500** in step **518**. If the reading is not finished, the returned Boolean value (i.e., NOT DONE) causes the radio to continue receiving response signals, passing control to step **508**.

Association of RFID Tag Data With Item Using Machine-Readable Symbol

Often a user desires to make a physical association between the data read from one of the RFID tags **12A, 12B** and a particular object or item **14** (FIG. **1**). While the RFID tag **12A, 12B** may be attached to, or contained with the item, it can be difficult to identify the particular RFID tag **12A, 12B** that is being read. For example, trying to identify one or more bags in a cargo hold, or cargo container on an airliner is difficult and time consuming using only RFID tags **12A, 12B**. Each bag would have to be isolated and the RFID tag **12A, 12B** read to ensure that the read data came from the RFID tag **12A, 12B** associated with the particular bag. At least one proposed solution involves placing human-perceptible indicators on each of the RFID tags, as disclosed in the commonly assigned U.S. patent application Ser. No. 09/249,359, filed Feb. 12, 1999, entitled, "METHOD AND APPARATUS FOR HUMAN-PERCEPTIBLE IDENTIFICATION OF MEMORY DEVICES, SUCH AS RFID TAGS" (Atty. Docket No. 480062.663). This solution can be relatively expensive since each RFID tag **12A, 12B** requires its own human-perceptible indicator which complicates RFID tag manufacture.

FIG. **13** shows a method **600** of associating the read data from the RFID tag **12A, 12B** with a particular one of the items **14**. The association method **600** assumes that an RFID tag **12A, 12B** has already been read, a characteristic data string retrieved and stored, for example, in the characteristic data string, buffer **49**. The user can start the association method **600** in step **602**, as discussed generally above. Alternatively, the reader **10** can be configured to automatically start the association method **600** at step **602**. In step **668**, the microprocessor **46** enters the symbol reading, mode. The user activates the trigger **20** in step **670**, causing the microprocessor **46** to activate the image sensor **52** to read the machine-readable symbol **24A, 24B** at which the reader **10** is directed. In step **672**, the image sensor **52** acquires data from the machine-readable symbol **24A, 24B** by scanning, digitizing, or by any commonly known methods in the relevant art. As part of acquiring the data, the microprocessor **46**, or a dedicated processor (not shown), decodes the image to acquire a characteristic data stringy encoded in the machine-readable symbol **24A, 24B**. Methods and apparatus for acquiring data from machine-readable symbols are commonly known in the art, and are specifically taught in *The Bar Code Handbook* 3rd ED., by Palmer, Roger C, Helmers Publishing, Inc. (ISBN 0-911261-09-5), and, in the interest of brevity, will not be described in further detail.

To determine whether the machine-readable symbol **24A, 24B** that the reader **10** is pointing at is associated with the RFID tag data read by the reader **10**, the microprocessor **46** compares a characteristic data string read from the RFID tag, **12A, 12B** with the characteristic data string read from the machine-readable symbol **24A, 24B**, in step **620**. The user can visually associate the RFID tag **12A, 12B** with the machine-readable symbol **24A, 24B** since the RFID tag **12A** includes the machine-readable symbol **24A**, or the RFID tag **12B** and machine-readable symbol **24B** are carried by the same item **14**, or can be visually associated is some other manner. The user can therefore determine that the data is from a particular RFID tag **12A, 12B** when a match is indicated by the reader **10**.

If the characteristic data string from the machine-readable symbol **24A, 24B** corresponds to, or matches, the characteristic data string from the RFID tag **12A,12B**, the reader **10** provides an indication that an association exists. To provide the indication, the microprocessor **46** activates the speaker **66** to emit a single "beep" in step **614** and activates or "flashes" the Green RFID related LED **76** and the Green symbol related LED **78** in step **674**. The RFID related and the symbol related LEDs **76, 78** are each activated, indicating that both an RFID tag **12A, 12B** and a machine-readable symbol **24A, 24B** have been located, providing a consistency across the user interface.

In step **676**, the microprocessor **46** can turn OFF the image sensor **52** after having found an association. In step **612**, the reader **10** can report the data, for example transmitting the RFID data to the host **23** via the communications port **38** and interface **22**. In step **676**, the reader **10** can receive a direction or command from the host **23** via the interface **22** and the communications port **38**. In step **678**, the microprocessor **46** determines whether the buffer should be modified based on the command from the host **23**. If the buffer is to be modified, the microprocessor **46** modifies the buffer at step **680**, and passes control to an end of the association method **600** in step **618**. Otherwise, the microprocessor **46** passes control directly to the end of the association method, in step **600**, without modifying the buffer.

If the characteristic data string from the machine-readable symbol **24A**, **24B** does not correspond to, or match the characteristic data string from the RFID tag **12A**,**12B**, the reader **10** provides an indication that an association does not exist. To provide the indication, the microprocessor **46** activates the speaker **66** to emit a three "Beeps" in step **682**, and activates or "flashes" the Red RFID related LED **84** and the Green symbol related LED **78** in steps **626**, **684**, respectively. The Green symbol related LED **78** is flashed to indicate that a symbol has been successfully read, while the Red RFID related **84** is flashed to indicate that the data is not associated with the machine-readable symbol **24A**, **24B**, further providing consistency across the user interface. The microprocessor **46** proceeds to the end of the method **600**, in step **618**.

Automatically Reading A Symbol Based On Proximity To RFID Tag, or Frequency of RFID Tag's Responses

FIG. **14** shows a method **700**, in which the reader **10** automatically reads the machine-readable symbol when the reader **10** is within a defined proximity of the RFID tag **12A**, and hence within the defined proximity of the machine-readable symbol **24A**. The automated symbol reading feature provides numerous benefits, for example the automated symbol reading feature can simplify operation of the reader, and/or reduce the probability of user error. The automated symbol reading feature can also reduce the amount of labor required to operate the reader **10**, and can even eliminate the need for a human operator. The method **700** of FIG. **14** can be used as part of, or with, many of the previously described methods.

The antenna **42** in the reader **10** can be directionally sensitive. The directionally sensitive antenna **42** has a directional range, in other words, the antenna is more sensitive in certain directions than other directions. As the reader **10** approaches a particular RFID tag **12A**, **12B**, that RFID tag **12A**, **12B** spends a higher percentage of time within the range of the reader **10**. In contrast, other RFID tags **12A**, **12B** are in the range a lower percentage of time. Thus, as the reader **10** comes within a predefined proximity of the RFID tag **12A**, **12B**, the number of "hits" (i.e., reading an RFID tag having a desired characteristic data string) will increase, and the number of "misses" (i.e., reading RFID tags not having the desired characteristic data string) will decrease. The user may recognize this from an increase in the number of "Beeps" and a decrease in the number of "Clicks" emitted by the reader **10**. The microprocessor **46** in the reader **10**, can keep track of the number of hits and the number of misses for some unit length of time, steps **786**, **788**, respectively. The microprocessor **46** can determine a ratio of the number of hits per unit of time and the number of misses per unit of time. Alternatively, the host **23** can process the same information.

In step **790**, the microprocessor **46** determines whether the ratio of hits to misses exceeds a symbol reading threshold. If the ratio does not exceed the symbol reading threshold, the microprocessor **46** returns to step **786** and the reader **10** continues to read the RFID tags **12A**, **12B**, continually revising and checking the ratio against the threshold.

If the ratio exceeds the symbol reading threshold, the microprocessor **46** turns the image sensor **52** ON, for example, switching from the RFID reading mode to the symbol reading mode in step **768**. The microprocessor **46** controls the image sensor **52** to image and decode the machine-readable symbol **24A**, **24B** in **772**. In step **774**, the microprocessor **46** turns the image sensor **52** OFF, thereby conserving power. In step **720**, the microprocessor **46** compares the characteristic data string from the machine-readable symbol **24A**, **24B** to the characteristic data string from the RFID tag **12A**, **12B**.

If the characteristic data string from the machine-readable symbol **24A**, **24B** corresponds to, or matches, the characteristic data string from the RFID tag **12A**, **12B**, the reader **10** provides an indication that an association exists. To provide the indication, the microprocessor **46** activates the speaker **66** to emit a single "Beep" in step **714** and activates or "flashes" the Green RFID related LED **76** and the Green symbol related LED **78** in step **774**. The RFID related and the symbol related LEDs **76**, **78** are each activated, indicating that both an RFID tag **12A**, **12B** and a machine-readable symbol **24A**, **24B** have been located, providing a consistency across the user interface.

In **712**, the reader **10** can report the data, for example automatically transmitting the RFID data to the host **23** via the communications port **38** and interface **22**. In step **776**, the reader **10** can receive a direction or command from the host **23** via the interface **22** and the communications port **38**. In step **778**, the microprocessor **46** determines whether the characteristic data string buffer **49** should be modified based on the command from the host **23**. If the buffer **49** is to be modified, the microprocessor **46** modifies the buffer at step **780**, and passes control to an end of the association method **700** at step **718**. Otherwise, the microprocessor **46** passes control directly to the end of the association method **700** at step **718** without modifying the characteristic data string buffer **49**.

If the characteristic data string from the machine-readable symbol **24A**, **24B** does not correspond to, or match the characteristic data string from the RFID tag **12A**,**12B**, the reader **10** provides an indication that the association does not exist. The microprocessor **46** activates the speaker **66** to emit three "Beeps" in step **782**, and activates or "flashes" the Green symbol related LED **78** and the Red RFID related LED **84** in steps **784** and **726**, respectively. The Green symbol related LED **78** is flashed to indicate that a symbol has been successfully read, while the Red RFID related **84** is flashed to indicate that the data is not associated with the machine-readable symbol **24A**, **24B**, further providing consistency across the user interface.

SUMMARY

The various embodiments described above can be combined to provide further embodiments. All of the above U.S. patents, patent applications and publications referred to in this specification are incorporated by reference. Aspects of the invention can be modified, if necessary, to employ systems, circuits and concepts of the various patents, applications and publications to provide yet further embodiments of the invention.

Although specific embodiments of and examples data carrier readers and reading are described herein for illustrative purposes, various equivalent modifications can be made without departing from the spirit and scope of the invention, as will be recognized by those skilled in the relevant art. The teachings provided herein of the invention can be applied to any data carrier reader, not necessarily the exemplary combination RFID tag and symbol reader generally described above.

For example, some of the structures and methods can be used with readers capable of reading only RFID tags. Some of the structures and methods can be used with readers capable of reading only machine-readable symbols. Some of the structures and methods can be suitable with readers for other data carriers, such as optical tags and touch memory devices. The methods and structures are generally applicable with other wireless memory devices, not just radio frequency, and the term RFID as used herein is meant encompass wireless memory devices operating in all ranges of the electromagnetic spectrum, not only the radio frequency portion. Similarly, the structures and methods disclosed can work with any variety of modulation techniques, including, but not limited to, amplitude modulation, frequency modulation, phase modulation and/or pulse width modulation. The structures and methods can also be applied to various machine-readable symbologies, including, but not limited to, bar codes, stacked codes, area and/or matrix codes. The image sensor **52** can be any type of image capture device, including laser scanners, one- and two-dimensional charged coupled devices, Vidicons, and the like.

These and other changes can be made to the invention in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims, but should be construed to include all apparatus and methods that operate in accordance with the claims. Accordingly, the invention is not limited by the disclosure, but instead its scope is to be determined entirely by the following claims.

We claim:

1. A method of automatically searching RFID tags, comprising:

storing a number of characteristic data strings in a buffer;

reading a respective characteristic data string from each of a number of RFID tags; and

identifying any of the RFID tags that have the respective characteristic data strings that correspond to the characteristic data strings stored in the buffer after reading the respective characteristic data strings from at least two of the number of RFID tags.

2. The method of claim **1** wherein identifying the RFID tags includes comparing at least a portion of each of the read characteristic data strings to at least one of the characteristic data strings stored in the buffer.

3. The method of claim **1**, further comprising:

producing a human-perceptible indication corresponding to the number of identified RFID tags.

4. The method of claim **1**, further comprising:

producing a human-perceptible indication for each of the identified RFID tags.

5. The method of claim **1**, further comprising:

producing a human-perceptible indication having a characteristic that varies corresponding to the number of identified RFID tags.

6. The method of claim **1**, further comprising:

producing a second human-perceptible indication each time one of the read characteristic data strings matches at least one of the characteristic data strings stored in the memory.

7. The method of claim **1**, further comprising:

producing a second human-perceptible indication if all of the characteristic data strings stored in the memory match at least a respective one the read characteristic data strings.

8. The method of claim **1**, further comprising:

relaying data from the identified RFID tags to a host computer.

9. The method of claim **1**, further comprising:

transmitting an enable signal to a first one of the RFID tags that has a respective characteristic data string that matches one of characteristic data strings stored in the memory, the enable signal comprising a command to activate a human-perceptible indicator on the first one of the RFID tags.

* * * * *

EXHIBIT I

US006812841B2

(12) **United States Patent**
Heinrich et al.

(10) **Patent No.: US 6,812,841 B2**
(45) **Date of Patent: Nov. 2, 2004**

(54) **PASSIVE RFID TAG THAT RETAINS STATE AFTER TEMPORARY LOSS OF POWER**

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(73) Assignee: **Intermec IP Corp.**, Woodland Hills, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 243 days.

(21) Appl. No.: **10/056,398**

(22) Filed: **Jan. 23, 2002**

(65) **Prior Publication Data**

US 2003/0137400 A1 Jul. 24, 2003

(51) **Int. Cl.**[7] **G08B 13/14**
(52) **U.S. Cl.** **340/572.1**; 340/7.32; 340/10.1
(58) **Field of Search** 340/572.1, 693.1, 340/10.1, 7.32; 365/192

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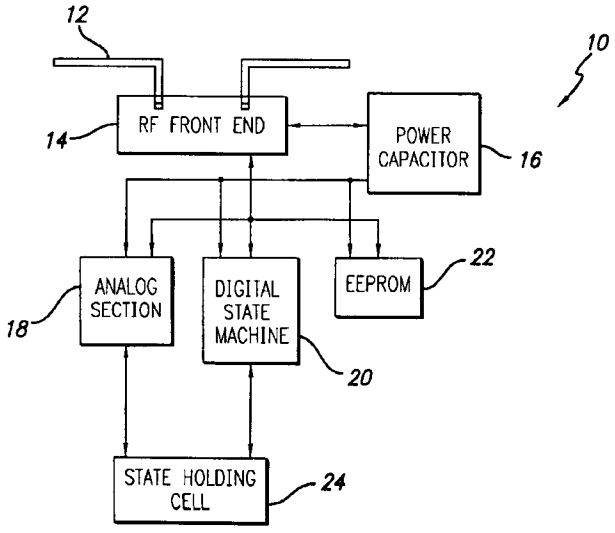
(74) *Attorney, Agent, or Firm*—O'Melveny & Myers LLP

(57) **ABSTRACT**

The present invention provides an RFID transponder that includes a state holding cell that maintains the present state of the RFID transponder during temporary losses of power. After power is restored to the RFID transponder, the state holding cell restores the present state to the RFID transponder so that transactions with an RFID interrogator can continue without having re-transmit redundant commands. The RFID transponder further comprises an RF front end adapted to receive an interrogating RF signal. An analog circuit is coupled to the RF front end and is adapted to recover analog signals from the received interrogating RF signal. The analog circuit provides state information defining a desired state of the RFID transponder corresponding to the analog signals. A digital state machine is coupled to the analog circuit and adapted to execute at least one command in accordance with the state information. A memory is coupled to the digital state machine and is adapted to store and retrieve digital data responsive to the at least one command executed by the digital state machine. A power capacitor is coupled to the RF front end and derives a voltage rectified from the interrogating RF signal to charge the power capacitor. The power capacitor thereby provides electrical power for the analog circuit, the digital state machine and the memory. The state holding cell is coupled to the analog circuit and the digital state machine and is adapted to maintain the state information during a loss in power provided by the power capacitor due to lapse in receipt of the interrogating RF signal by the RF front end.

24 Claims, 2 Drawing Sheets



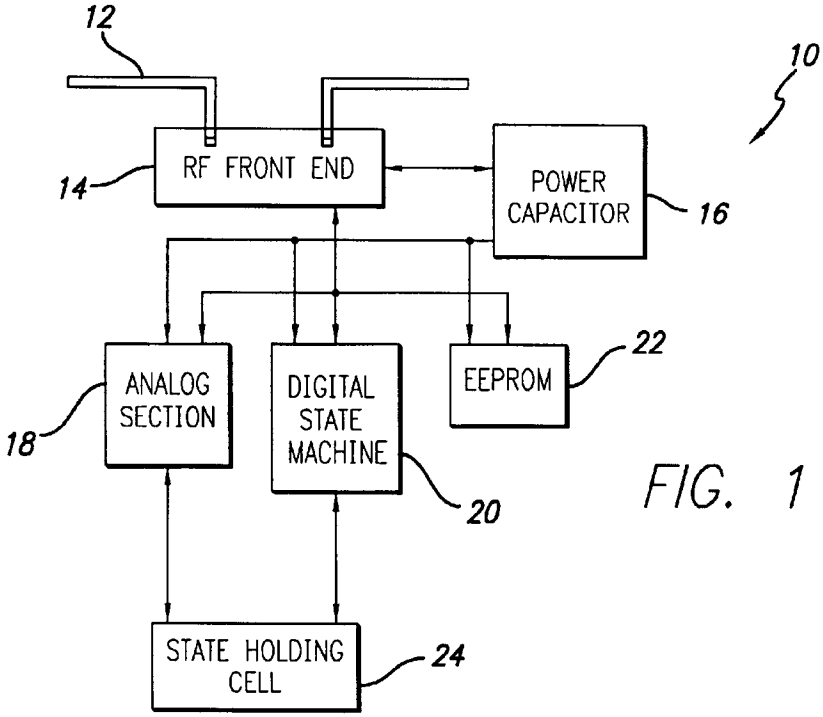

12
10
RF FRONT END
14
POWER CAPACITOR
16
ANALOG SECTION
18
DIGITAL STATE MACHINE
20
EEPROM
22
STATE HOLDING CELL
24

FIG. 1

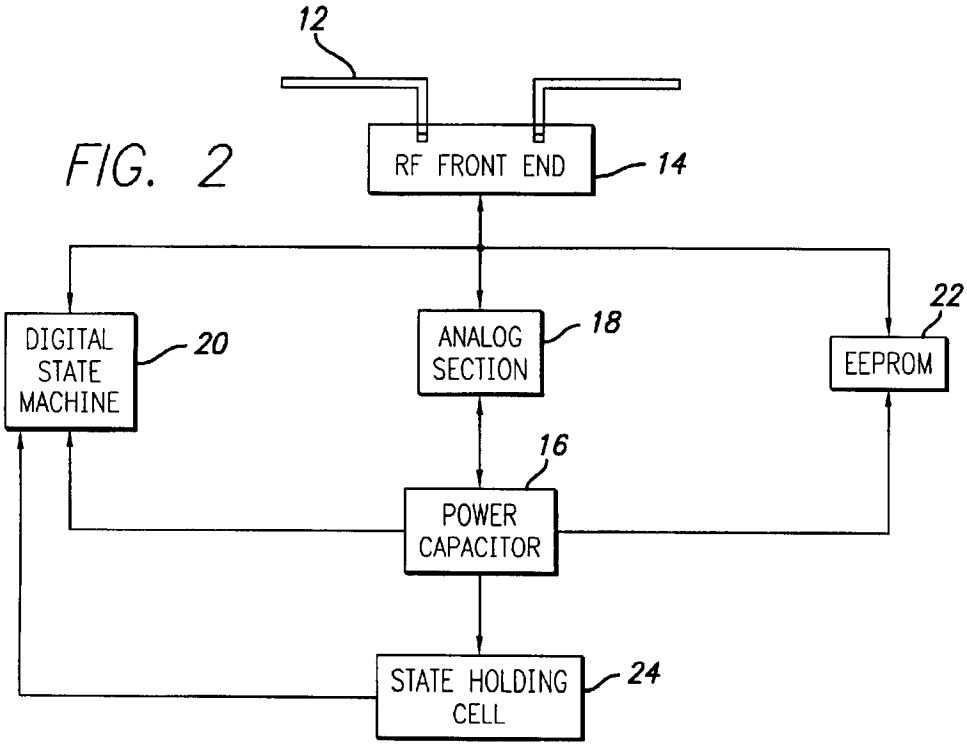
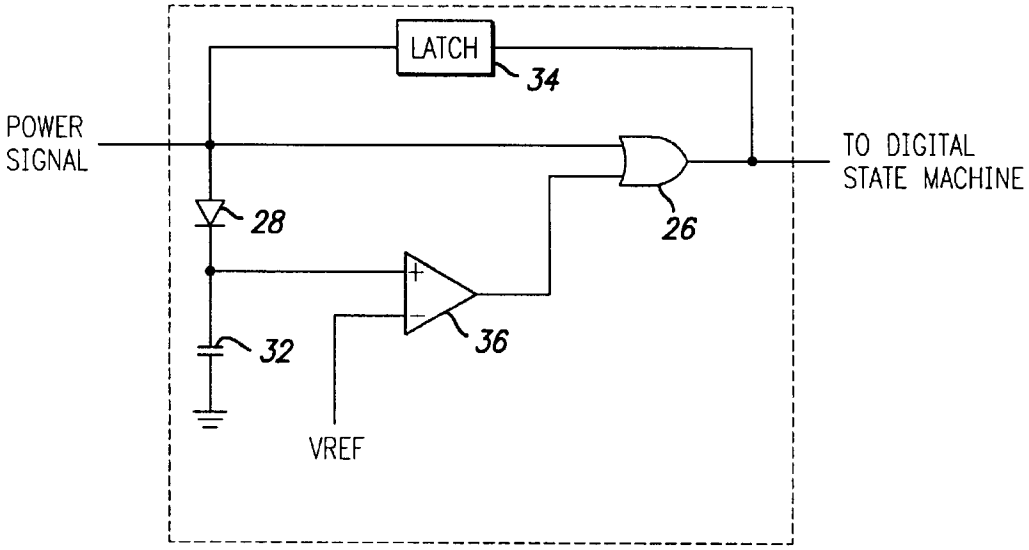

12
RF FRONT END
14
DIGITAL STATE MACHINE
20
ANALOG SECTION
18
EEPROM
22
16
POWER CAPACITOR
STATE HOLDING CELL
24

FIG. 2

FIG. 3


LATCH
34
POWER
SIGNAL
TO DIGITAL
STATE MACHINE
28
26
32
36
VREF

PASSIVE RFID TAG THAT RETAINS STATE AFTER TEMPORARY LOSS OF POWER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to radio frequency (RF) transponders, and more particularly, to a radio frequency identification (RFID) transponder that can preserve state information after losing power for a short period of time.

2. Description of Related Art

In the automatic data identification industry, the use of RFID transponders (also known as RFID tags) has grown in prominence as a way to track data regarding an object to which the RFID transponder is affixed. An RFID tag generally includes a semiconductor memory in which digital information may be stored, such as an electrically erasable, programmable read-only memory (EEPROM) or similar electronic memory device. An RFID interrogator or reader may recover the digital information stored in the RFID tag using modulated radio frequency (RF) signals. One such communication technique is referred to as "backscatter modulation," by which an RFID tag transmits stored data by reflecting varying amounts of an electromagnetic field provided by the RFID interrogator by modulating the antenna matching impedance of the tag. The RFID tag can therefore operate independently of the frequency of the energizing field, and as a result, the interrogator may operate at multiple frequencies so as to avoid RF interference, such as utilizing frequency hopping spread spectrum modulation techniques. Since RFID tags using backscatter modulation do not include a radio transceiver, they can be manufactured in very small, lightweight and hence inexpensive units.

RFID tags either extract their power from the electromagnetic field provided by the interrogator (also known as field-powered or "passive" RFID tags), or include their own internal power source (e.g., battery). Passive RFID tags that extract their power from the interrogating field are particularly cost effective since they lack a power source, and can be constructed in smaller package sizes. A drawback of passive RFID tags is that they are susceptible to temporary fluctuations in power level due to variations in the RF environment. More particularly, RFID tags are often utilized in a physical environment that contains various RF absorbing and reflecting surfaces, such as within a manufacturing facility or warehouse. An RFID interrogator may be utilized within such a location to interrogate all of the RFID tags present within the location. The RF absorbing and reflecting surfaces of the location cause multipath cancellation, i.e., the complete cancellation of signals due to the relative amplitude and phase differences of RF components traveling over separate paths. This multipath cancellation is further compounded by the use of a frequency hopping spread-spectrum RF field pattern emitted by the RFID interrogator. As a result of the multipath cancellation, there may be areas within the location in which the RF field strength is essentially zero. Thus, passive RFID tags disposed within or passing through these zero field strength areas will temporarily lose power. In applications in which the RFID tag is expected to maintain its state after it is powered, the temporary loss of power destroys the state information held by the RFID tag.

For example, certain RFID systems include a command set that enables an RFID interrogator to execute a number of functions on plural RFID tags within its range. Using certain commands within the command set, the RFID interrogator may be able to identify multiple RFID tags simultaneously,

or may be able to select a subset of RFID tags based on tag memory contents. These RFID tags may further include a state machine that undergoes transitions in the course of processing a command received from the RFID interrogator. When such an RFID tag momentarily loses power due to being within or passing through a zero field strength area, the internal information defining the state is lost. After the RFID tag power is restored, the tag may reinitialize in a state that is different than the state it was in prior to the loss of power. The RFID interrogator will have to repeat the transmission of commands to the RFID tag in order to restore the lost state and complete the desired transaction. This redundant transmission of commands results in an undesirable delay in communication between the RFID interrogator and tag. This communication delay particularly impacts RFID system protocols that identify the presence of multiple RFID tags within an environment, since the delay greatly increases the amount of time necessary to fully identify all of the tags.

In these and other RFID applications, it is very desirable to reduce the amount of time for accomplishing an identification transaction (and thereby increase the identification rate). It would therefore be advantageous to provide an RFID tag that can preserve state information after losing power for a short period of time.

SUMMARY OF THE INVENTION

The present invention provides an RFID transponder that includes a state holding cell that maintains the present state of the RFID transponder during temporary losses of power. After power is restored to the RFID transponder, the state holding cell restores the present state to the RFID transponder so that transactions with an RFID interrogator can continue without having to re-transmit redundant commands.

More particularly, the RFID transponder comprises an RF front end adapted to receive an interrogating RF signal. An analog circuit is coupled to the RF front end and is adapted to recover analog signals from the received interrogating RF signal. The analog circuit provides state information defining a desired state of the RFID transponder corresponding to the analog signals. A digital state machine is coupled to the analog circuit and adapted to execute at least one command in accordance with the state information. A memory is coupled to the digital state machine and is adapted to store and retrieve digital data responsive to at least one command executed by the digital state machine. A power capacitor is coupled to the RF front end and derives a voltage rectified from the interrogating RF signal to charge the power capacitor. In an alternative embodiment, the power capacitor derives the aforementioned rectified voltage from the interrogating RF signal via the analog circuit. Within such alternative embodiment, it should be appreciated that the power capacitor is not connected to the RF front end and is instead coupled between the state holding cell and the analog circuit. In either embodiment, however, the power capacitor provides electrical power for the analog circuit, the digital state machine and the memory. The state holding cell is coupled to the analog circuit and the digital state machine and is adapted to maintain the state information during a loss in power provided by the power capacitor due to lapse in receipt of the interrogating RF signal by the RF front end.

In an embodiment of the invention, the state holding cell further comprises an OR gate have a first input terminal operatively coupled to the analog circuit to receive a voltage corresponding to the state information, a second input terminal coupled to a capacitor, and an output terminal pro-

viding the state information to the digital state machine. The voltage charges the capacitor. A diode is coupled between the first input terminal and the second input terminal of the OR gate. A latch may also be coupled between the first input terminal and the output terminal of the OR gate. The latch is operative to restore the voltage corresponding to the state information to the first input terminal following the temporary lapse in receipt of the interrogating RF signal.

A more complete understanding of the passive RFID tag that retains state after temporary loss of power will be afforded to those skilled in the art, as well as a realization of additional advantages and objects thereof, by a consideration of the following detailed description of the preferred embodiment. Reference will be made to the appended sheets of drawings which will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an RFID tag having a state holding cell in accordance with an embodiment of the invention;

FIG. **2** is a block diagram of an RFID tag having a state holding cell in accordance with another embodiment of the invention; and

FIG. **3** is an electrical schematic diagram of an exemplary state holding cell.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention satisfies the need for an RFID tag that can preserve state information after losing power for a short period of time. In the detailed description that follows, like element numerals are used to describe like elements illustrated in one or more of the figures.

Referring first to FIG. **1**, a block diagram is shown of an exemplary RFID tag **10** in accordance with an embodiment of the present invention. The exemplary RFID tag **10** includes an RF front end **14**, a power capacitor **16**, an analog section **18**, a digital state machine **20**, a memory **22**, and a state holding cell **24**. The RF front end **14** is coupled to an antenna **12**, and may include an RF receiver that recovers analog signals that are transmitted by an RFID interrogator and an RF transmitter that sends data signals back to the RFID interrogator. The RF transmitter may further comprise a modulator adapted to backscatter modulate the impedance match with the antenna **12** in order to transmit data signals by reflecting a continuous wave (CW) signal provided by the RFID interrogator. As shown in FIG. **1**, the antenna **12** comprises a dipole, but it should be appreciated that other types of antennas could also be advantageously utilized, such as a folded dipole, a meander dipole, a dipole over ground plane, a patch, and the like. The RF field provided by the RFID interrogator presents a voltage on the antenna **12** that is rectified by the RF front end **14** and used to charge the power capacitor **16**. The power capacitor **16** serves as a voltage source for the analog section **18**, digital state machine **20** and the memory **22** of the RFID tag **10**.

The analog section **18** converts analog data signals recovered by the RF front end **14** into digital signals comprising the received commands, recovers a clock from the received analog signals, and converts digital data retrieved from the memory **22** into analog signals that are backscatter modulated by the RF front end **14**. The digital state machine **20** provides logic that controls the functions of the RFID tag **10** in response to commands provided by the RFID interrogator that are embedded in the recovered RF signals. The digital state machine **20** accesses the memory **22** to read and/or write data therefrom. The memory **22** may be provided by an EEPROM or like semiconductor memory device capable of maintaining a stored data state in absence of an applied voltage. The RF front end **14**, analog section **18**, digital state machine **20**, and memory **22** communicate with each other through respective input/output (I/O) buses, or alternatively, a common I/O bus may carry all such communications. It should be appreciated that the RF front end **14**, analog section **18**, digital state machine **20**, memory **22**, and the state holding cell **24** (discussed below) may be provided by separate circuit elements, or may be sub-elements of a single mixed-signal integrated circuit, such as an application specific integrated circuit (ASIC), field programmable gate array (FPGA), and the like. The state holding cell **24** is coupled between the analog section **18** and the digital state machine **20**.

As discussed above, analog signals recovered by the analog section **18** include commands provided by the RFID interrogator that are then executed by the digital state machine **20**. Certain ones of these commands cause the RFID tag **10** to change state. Exemplary states for the RFID tag **10** include: (i) ready state, when the tag is first powered up; (ii) identification state, when the tag is trying to identify itself to the RFID interrogator; and, (iii) data exchange state, when the tag is known to the RFID interrogator and is either reading data from memory or writing data to memory. Other tag states may also be included. The state determines how a given command is executed by the RFID tag **10**. For example, an initialization command may be executed by an RFID tag in any of the aforementioned states, while a command to lock a byte of memory will generally be executed contingent upon the RFID tag being advanced to the data exchange state. The state may be defined by a digital value (e.g., one or two bits in length). In a conventional RFID tag, a temporary loss of power to the digital state machine after the tag has advanced to the identification state or the data exchange state, such as by the tag passing through a zero RF field region, will cause the RFID tag to return to the ready state upon restoration of power.

In an embodiment of the present invention, the state holding cell **24** provides a storage location for the state information. As the analog section **18** recovers commands that are passed to the digital state machine **20** for execution, state information is also passed to the state holding cell **24**. In the event of a temporary loss of power to the RFID tag **10**, the digital state machine **20** can restore the state existing prior to the loss of power by accessing the state information contained within the state holding cell **24**.

In an alternative embodiment, the power capacitor **16** is coupled between analog section **18** and state holding cell **24** as shown in FIG. **2**. The rectified voltage provided by the RF front end **14** is used as a primary voltage source for the RFID tag **10**, while stored power in power capacitor **16** is used as a secondary voltage source in the event of a temporary loss of power. Hence, power capacitor **16** becomes the only voltage source for the analog section **18**, digital state machine **20** and the memory **22** of the RFID tag **10** whenever a primary voltage source is not available.

Referring now to FIG. **3**, an electrical schematic diagram of an exemplary state holding cell **24** is provided. The exemplary state holding cell **24** comprises an OR gate **26**, a diode **28**, a capacitor **32**, and an operational amplifier **36**. A first input terminal of the OR gate **26** is coupled to a power signal (received either from the analog section **18** as described in FIG. **1** or from the power capacitor **16** as described in FIG. **2**) in order to receive one data bit of the

state information. The diode **28** is coupled between a first input terminal of the OR gate **26** and the positive input terminal of the operational amplifier **36**. The capacitor **32** is coupled between the positive input terminal of the operational amplifier **36** and ground. A reference voltage VREF is then provided to the negative input terminal of the operational amplifier **36** while the output terminal of operational amplifier **36** is connected to a second input terminal of the OR gate **26**. An output terminal of the OR gate **26** is coupled to the digital state machine **20** to receive the state information upon the event of a temporary loss of power by the RFID tag **10**. In a preferred embodiment of the invention, diode **28** is provided by a p-n junction diode. Although alternative embodiments may substitute Schottky diodes for p-n junction diodes, it should be appreciated that p-n junction diodes are preferred due to their more favorable reverse leakage characteristics. For convenience, the following discussion will apply to a single data bit of the state information, but it should be noted that there would be another circuit identical to that shown in FIG. **3** corresponding to each other data bit of the state information.

When the received power signal corresponds to a data ONE, the OR gate **26** will have a data ONE at the output terminal. The voltage present at the first input terminal of the OR gate **26** will charge the capacitor **32** through the diode **28**, until the voltage across the capacitor substantially mirrors the voltage at the first input terminal (minus the small voltage drop across the diode **28**). The voltage at the second input terminal of the OR gate **26** (i.e., at the output of the operational amplifier **36**) will then also represent a data ONE, but the output terminal of the OR gate **26** will remain at data ONE. In the event of a temporary loss of power to the RFID tag **10**, the received power signal applied to the first input terminal of the OR gate **26** will fall to a data ZERO. Nevertheless, the output terminal of the OR gate **26** will remain at data ONE due to the charge on the capacitor **32** that maintains the second input terminal at data ONE via the operational amplifier **36**. The diode **28** prevents discharge of the capacitor **32** back through the analog section **18**. The duration of time that the state holding cell will maintain the previous state information will be determined by the leakage characteristics of the capacitor **32** and other parasitic elements of the circuit. After power is restored to the RFID tag **10**, the digital state machine **20** recovers the state information from the output terminal of the OR gate **26**. It should be appreciated that a received power signal corresponding to a data ZERO will result in the output terminal of the OR gate **26** remaining at data ZERO since the capacitor **32** will not be charged.

In a preferred embodiment, it should be appreciated that the operational amplifier **36** is used as a voltage comparator circuit. More specifically, the operational amplifier **36** is used in cases where stray leakage may cause the voltage on capacitor **32** to drop to levels in which OR gate **26** is not activated. In such cases, the reference voltage VREF that is provided to the negative terminal of operational amplifier **36** is used to generate an amplified version of the voltage stored in capacitor **32**. In particular, the operational amplifier **36** compares the voltage across the capacitor **32** to the reference voltage VREF. If the voltage across the capacitor **32** is greater than the reference voltage VREF, then the operational amplifier **36** outputs a high voltage corresponding to a data ONE; otherwise, a low voltage corresponding to a data ZERO is output. This output voltage is then provided as input to the second input terminal of the OR gate **26** as described above.

The state holding cell may further include a latch **34** coupled between the first input terminal and the output terminal of the OR gate **26**. The latch **34** would be used after power is restored to the RFID tag **10** to return the first input terminal of the OR gate **26** to the data state it was in prior to the loss of power. The latch **34** may be provided by a conventional S-R latch or flip-flop circuit. For a flip-flop circuit, it may be necessary to have a clock signal generated by the digital state machine **20** to trigger the flip-flop to apply the data state of the output terminal of the OR gate **26** to the first input terminal. An S-R latch would not require an additional signal to apply the data state.

Having thus described a preferred embodiment of a passive RFID tag that retains state after temporary loss of power, it should be apparent to those skilled in the art that certain advantages of the described system have been achieved. It should also be appreciated that various modifications, adaptations, and alternative embodiments thereof may be made within the scope and spirit of the present invention. The invention is further defined by the following claims.

What is claimed is:

1. An RFID transponder, comprising:

an RF front end adapted to receive an interrogating RF signal;

an analog circuit coupled to said RF front end and adapted to recover analog signals from said received interrogating RF signal, said analog circuit providing state information defining a desired state of said RFID transponder corresponding to said analog signals;

a digital state machine coupled to said analog circuit and adapted to execute at least one command in accordance with said state information;

a memory coupled to said digital state machine and adapted to store and retrieve digital data responsive to said at least one command executed by said digital state machine

a power capacitor coupled to said analog circuit and deriving a voltage rectified from said interrogating RF signal to charge said power capacitor, said power capacitor thereby providing electrical power for said analog circuit, said digital state machine and said memory; and

a state holding cell coupled to said digital state machine and being adapted to maintain said state information during a loss in power provided by said power capacitor due to lapse in receipt of said interrogating RF signal by said RF front end.

2. The RFID transponder of claim **1**, wherein said state holding cell further comprises an OR gate having a first input terminal operatively coupled to receive a voltage corresponding to said state information, a second input terminal coupled to a capacitor via a voltage comparator circuit having an input terminal and an output terminal, and an output terminal providing said state information to said digital state machine, said capacitor being charged by said voltage.

3. The RFID transponder of claim **2**, further comprising a diode coupled between said first input terminal and said input terminal of said voltage comparator circuit.

4. The RFID transponder of claim **3**, wherein said diode further comprises a Schottky diode.

5. The RFID transponder of claim **3**, wherein said diode further comprises a p-n junction diode.

6. The RFID transponder of claim **2**, further comprising a latch coupled between said first input terminal and said output terminal of said OR gate, said latch being operative to restore said voltage corresponding to said state informa-

tion to said first input terminal following said temporary lapse in receipt of said interrogating RF signal.

7. The RFID transponder of claim 1, wherein said memory further comprises an EEPROM device.

8. The RFID transponder of claim 1, wherein said state information defines plural operating states of said digital state machine.

9. An RFID transponder, comprising:

means for receiving an interrogating RF signal;

means for recovering analog signals from said received interrogating RF signal and providing state information defining a desired state of said RFID transponder corresponding to said analog signals;

means for executing at least one command in accordance with said state information;

means for storing and retrieving digital data responsive to said at least one command;

means for providing electrical power for said RFID transponder derived from said interrogating RF signal; and

means for maintaining said state information during a temporary lapse in receipt of said interrogating RF signal.

10. The RFID transponder of claim 9, wherein said receiving means further comprises an RF front end.

11. The RFID transponder of claim 9, wherein said recovering means further comprises an analog circuit.

12. The RFID transponder of claim 9, wherein said executing means further comprises a digital state machine.

13. The RFID transponder of claim 12, wherein said state information defines plural operating states of said digital state machine.

14. The RFID transponder of claim 9, wherein said storing and retrieving means further comprises a memory device.

15. The RFID transponder of claim 14, wherein said memory device further comprises an EEPROM device.

16. The RFID transponder of claim 9, wherein said maintaining means further comprises an OR gate having a first input terminal operatively coupled to receive a voltage corresponding to said state information, a second input terminal coupled to a capacitor, and an output terminal providing said state information, said capacitor being charged by said voltage.

17. The RFID transponder of claim 16, further comprising a diode coupled between said first input terminal and said input terminal of said OR gate.

18. The RFID transponder of claim 17, wherein said diode further comprises a Schottky diode.

19. The RFID transponder of claim 17, wherein said diode further comprises a p-n junction diode.

20. The RFID transponder of claim 16, further comprising a latch coupled between said first input terminal and said output terminal of said OR gate, said latch being operative to restore said voltage corresponding to said state information to said first input terminal following said temporary lapse in receipt of said interrogating RF signal.

21. A method for operating an RFID transponder, comprising the steps of:

receiving an interrogating RF signal;

recovering analog signals from said received interrogating RF signal and providing state information defining a desired state of said RFID transponder corresponding to said analog signals;

executing at least one command in accordance with said state information;

storing and retrieving digital data responsive to said at least one command;

providing electrical power for said RFID transponder derived from said interrogating RF signal; and

maintaining said state information during a temporary lapse in receipt of said interrogating RF signal.

22. The method of claim 21, wherein said maintaining step further comprises receiving a voltage corresponding to said state information, and charging a capacitor by said voltage.

23. The method of claim 22, further comprising the step of preventing discharge of said capacitor during said temporary lapse in receipt of said interrogating RF signal.

24. The method of claim 22, further comprising the step of restoring said voltage corresponding to said state information following said temporary lapse in receipt of said interrogating RF signal.

* * * * *

EXHIBIT J

US006812852B1

(12) **United States Patent**
Cesar

(10) **Patent No.: US 6,812,852 B1**
(45) **Date of Patent: *Nov. 2, 2004**

(54) **SYSTEM AND METHOD FOR SELECTING A SUBSET OF AUTONOMOUS AND INDEPENDENT SLAVE ENTITIES**

(75) Inventor: **Christian Lenz Cesar**, Shrub Oak, NY (US)

(73) Assignee: **Intermac IP Corp.**, Everett, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/179,481**

(22) Filed: **Oct. 27, 1998**

Related U.S. Application Data

(63) Continuation of application No. 08/646,539, filed on May 8, 1996, now Pat. No. 5,828,318, and a continuation-in-part of application No. 08/694,606, filed on Aug. 9, 1996, now Pat. No. 5,942,987, which is a continuation-in-part of application No. 08/303,965, filed on Sep. 9, 1994, now Pat. No. 5,673,037.

(51) **Int. Cl.**[7] **G08C 19/00**; G05B 23/02; G06F 13/00

(52) **U.S. Cl.** **340/825.69**; 340/3.51; 340/3.58; 710/110; 710/111

(58) **Field of Search** 340/825.69, 3.51, 340/3.52; 710/110, 111

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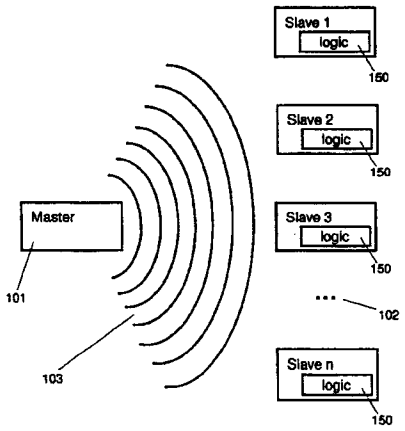
Primary Examiner—Brian Zimmerman
Assistant Examiner—Clara Yang

(57) **ABSTRACT**

A master entity is capable of broadcasting commands to a plurality of three-state-selection machine slaves. Transitions from one state to another are effected on instruction from commands in a sequence of commands broadcast from the master. Slaves move to another state when they satisfy a primitive condition specified in the command. By moving slaves among the three sets, a desired subset of slaves can be isolated in one of the sets. This desired subset of slaves then can be moved to one of the states that is unaffected by commands that cause the selection of other desirable subsets of slaves.

19 Claims, 31 Drawing Sheets



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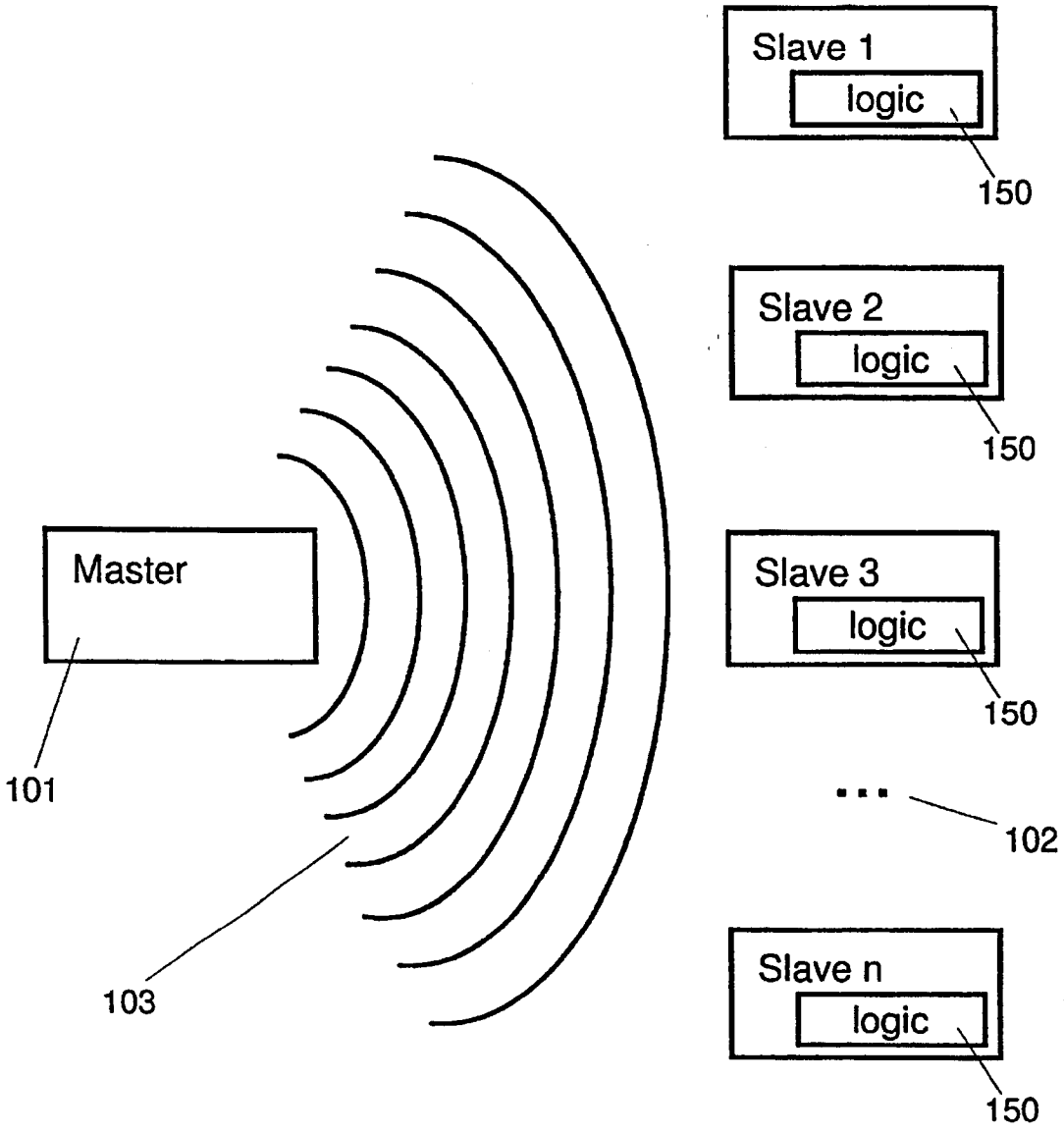
Slave 1
logic
150
Slave 2
logic
150
Master
Slave 3
logic
150
101
...
102
103
Slave n
logic
150

FIG. 1

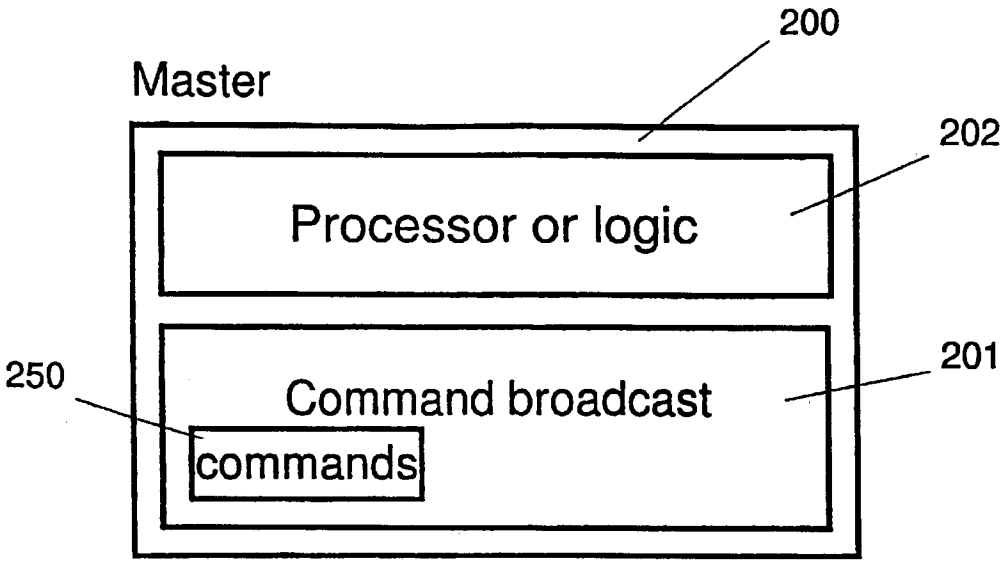
200
Master
202
Processor or logic
250
201
Command broadcast
commands

FIG. 2

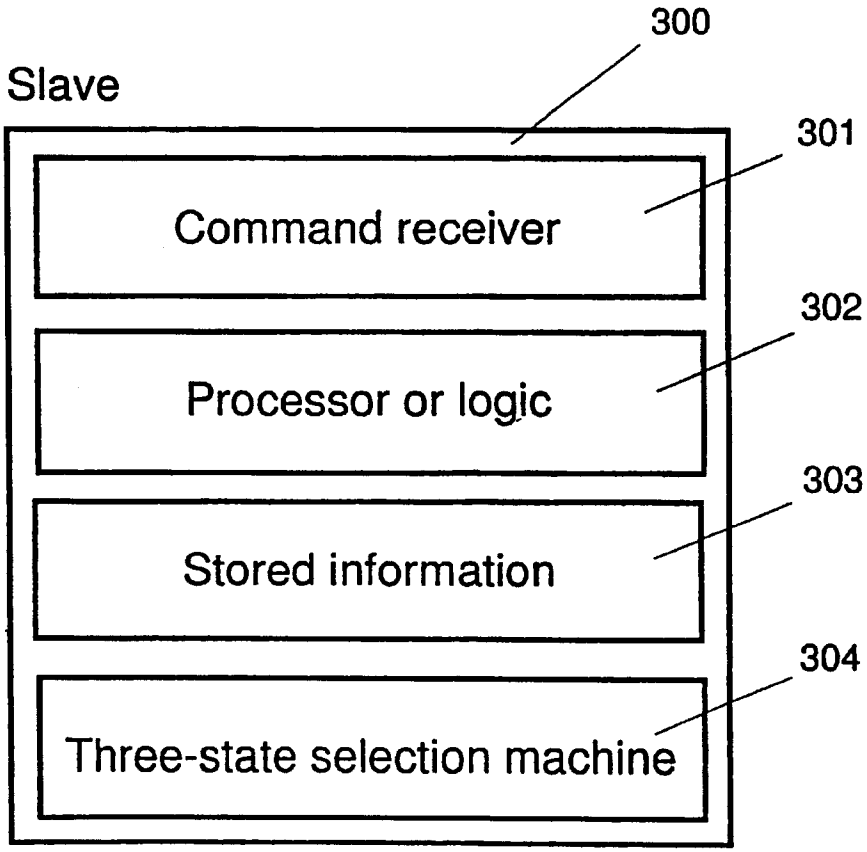
300
Slave
301
Command receiver
302
Processor or logic
303
Stored information
304
Three-state selection machine

FIG. 3

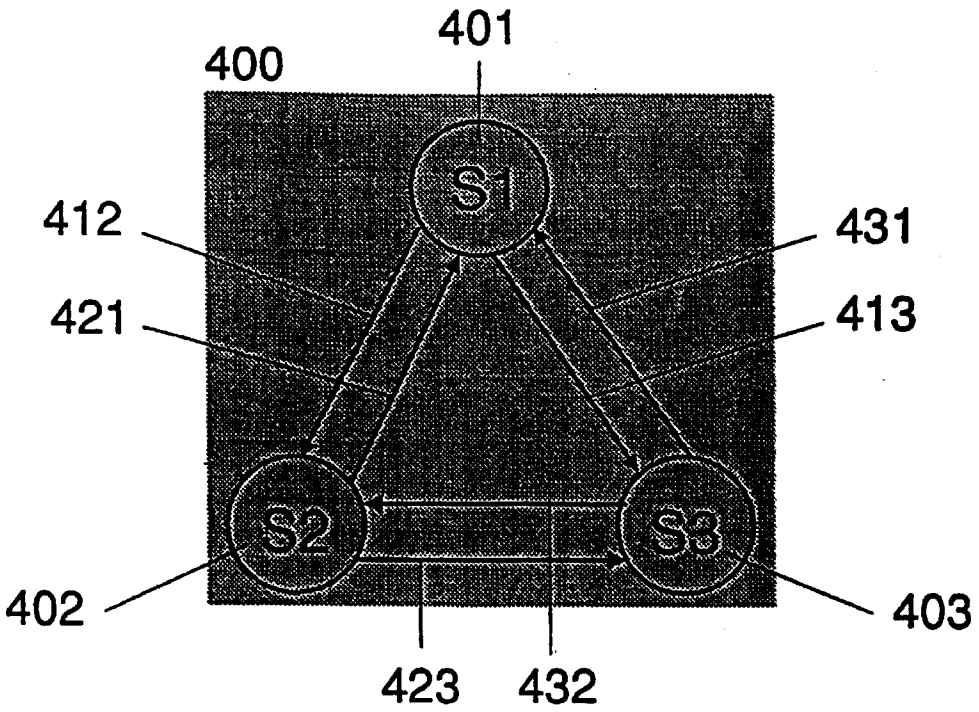
401
400
S1
412
431
421
413
S2
S3
402
403
423
432

FIG. 4

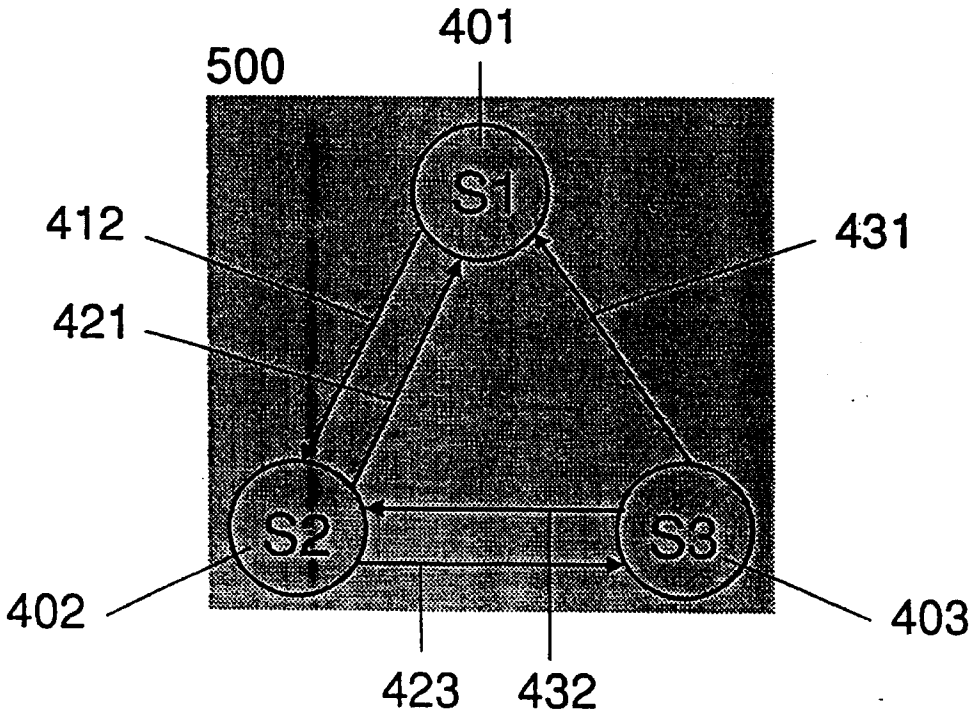
401
500
S1
412
431
421
S2
S3
402
403
423
432

FIG. 5

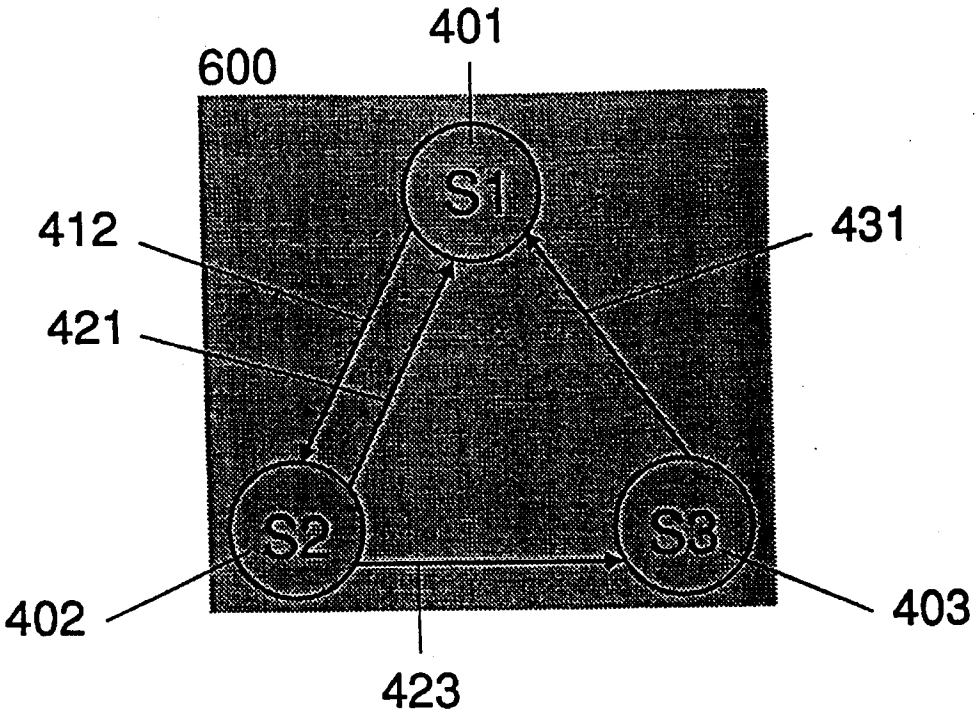
401
600
S1
412
431
421
S2
S3
402
403
423

FIG. 6

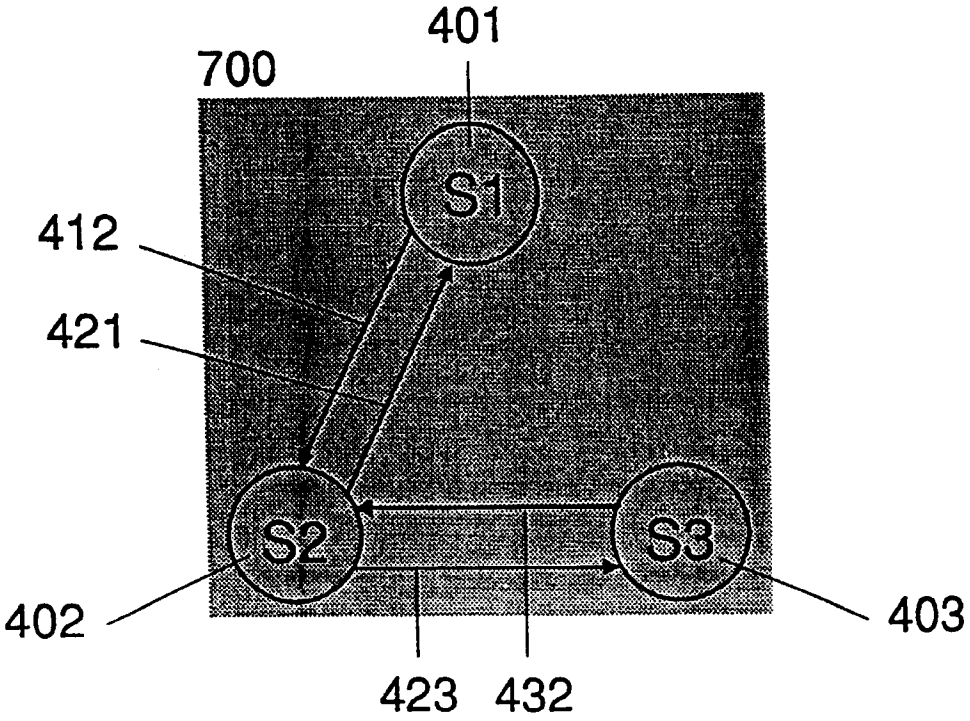
401
700
S1
412
421
S2
S3
402
403
423
432

FIG. 7

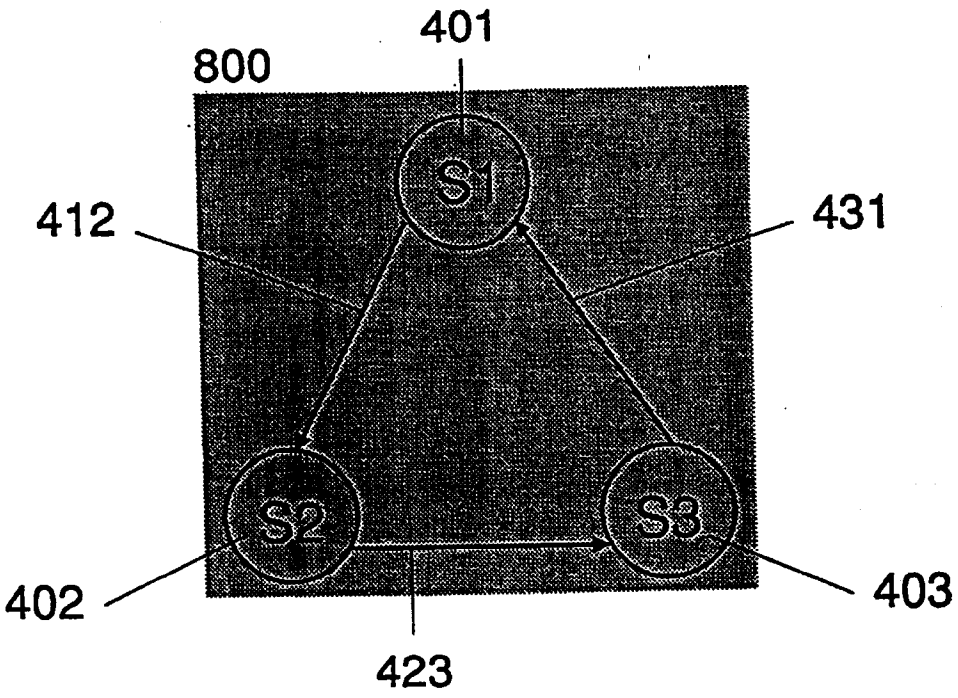

FIG. 8

	T12	T21	T23	T32	T31	T13
900	Yes	Yes	Yes	Yes	Yes	Yes
901	Yes	Yes	Yes	Yes	Yes	No
902	Yes	Yes	Yes	Yes	No	Yes
903	Yes	Yes	Yes	No	Yes	Yes
904	Yes	Yes	No	Yes	Yes	Yes
905	Yes	No	Yes	Yes	Yes	Yes
906	No	Yes	Yes	Yes	Yes	Yes
907	Yes	Yes	Yes	No	Yes	No
908	Yes	Yes	No	Yes	No	Yes
909	Yes	No	Yes	Yes	Yes	No
910	No	Yes	Yes	Yes	No	Yes
911	Yes	No	Yes	No	Yes	Yes
912	No	Yes	No	Yes	Yes	Yes
913	Yes	Yes	Yes	Yes	No	No
914	Yes	Yes	No	No	Yes	Yes
915	No	No	Yes	Yes	Yes	Yes
916	Yes	No	Yes	No	Yes	No
917	No	Yes	No	Yes	No	Yes

FIG. 9

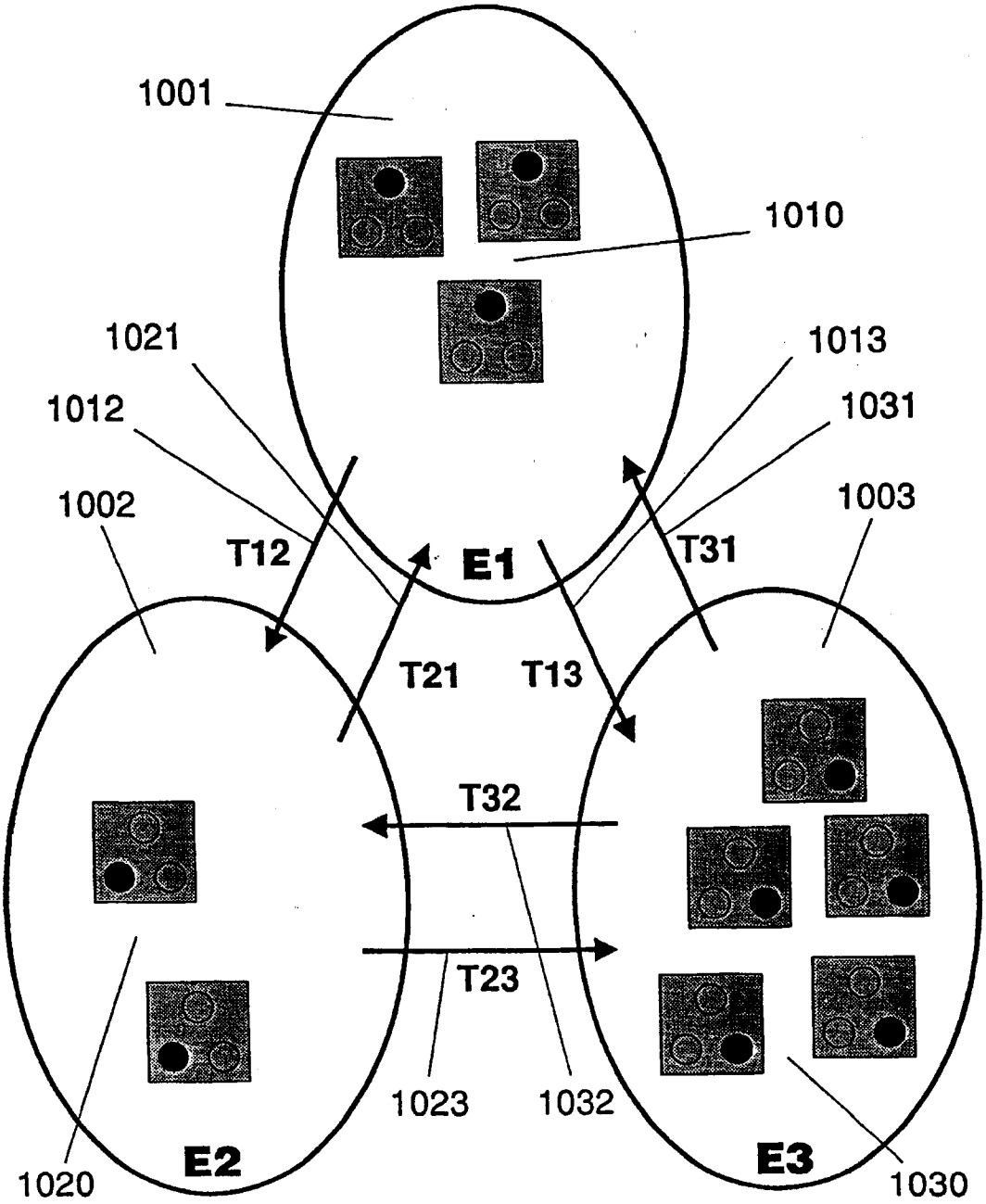
1001
1010
1021
1013
1012
1031
1002
1003
T12
E1
T31
T21
T13
T32
T23
1023
1032
1020
E2
E3
1030

FIG. 10

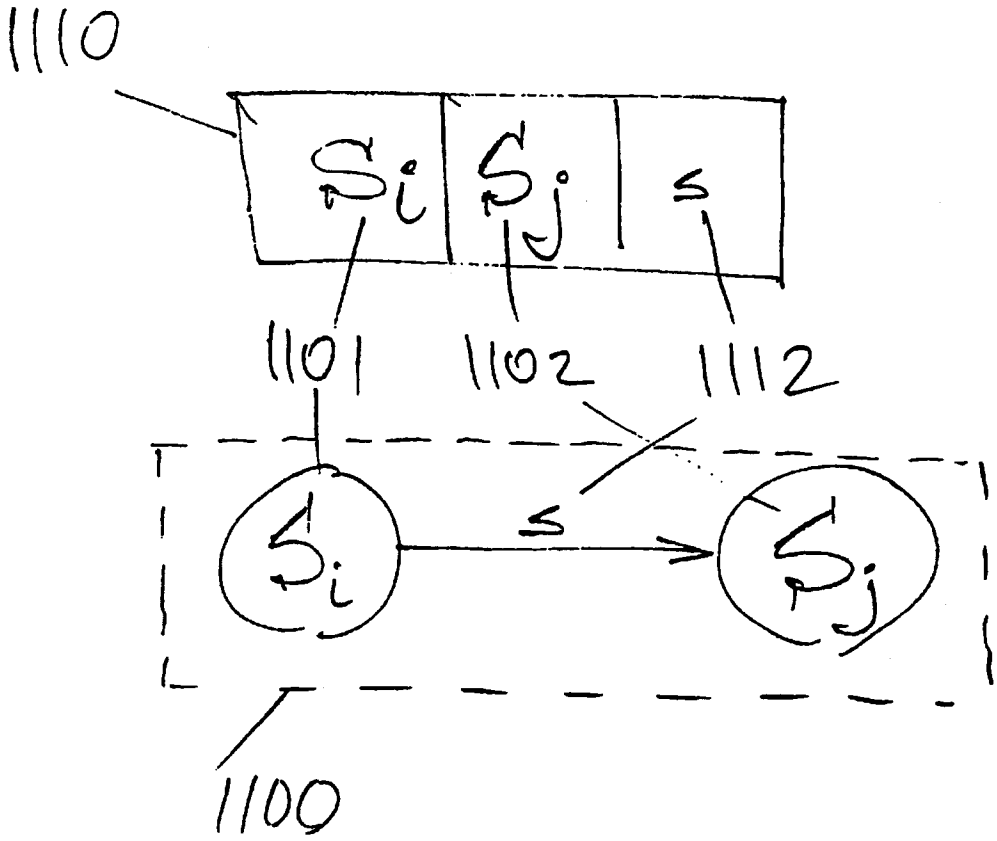

FIG. 11

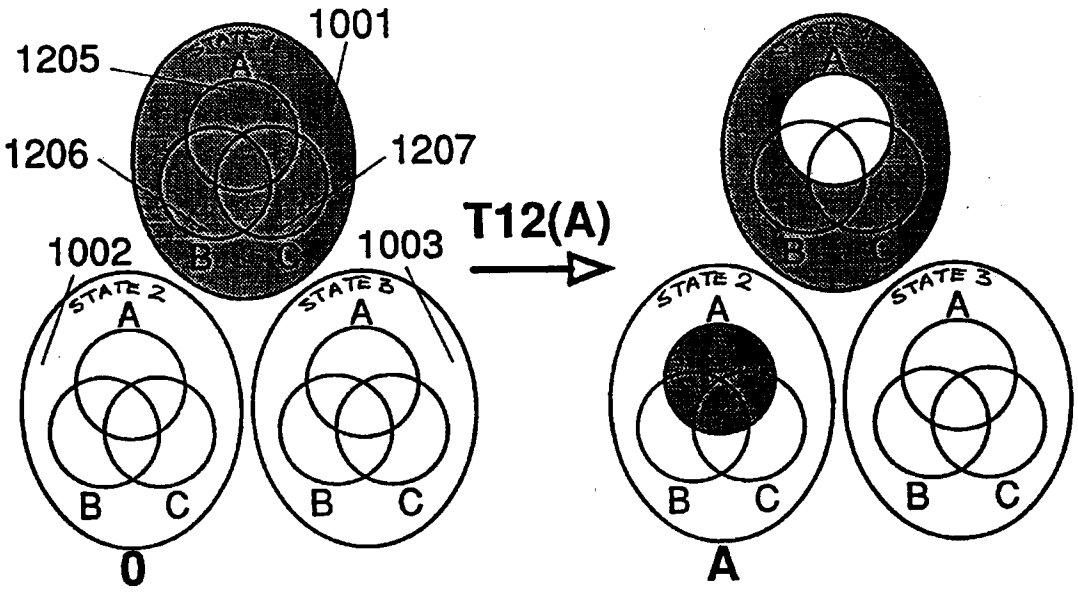
1001
1205
1206
1207
1002
1003
T12(A)
STATE 1
STATE 2
STATE 3
A
B
C
0
A

FIG. 12

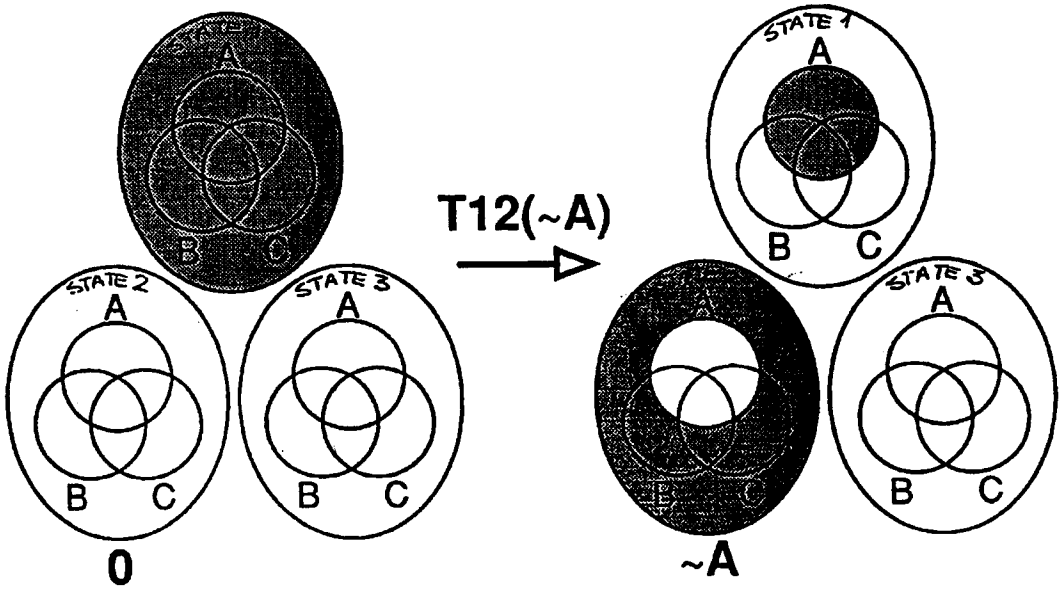
T12(~A)
STATE 1
STATE 2
STATE 3
A
B
C
0
~A

FIG. 13

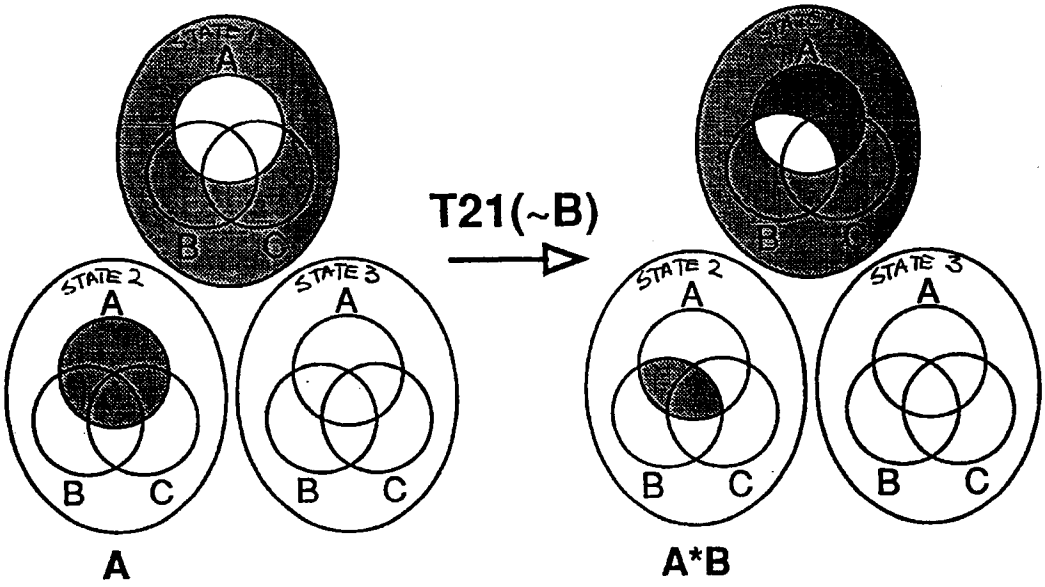
T21(~B)
STATE 2
A
B C
STATE 3
A
B C
A
A*B

FIG. 14

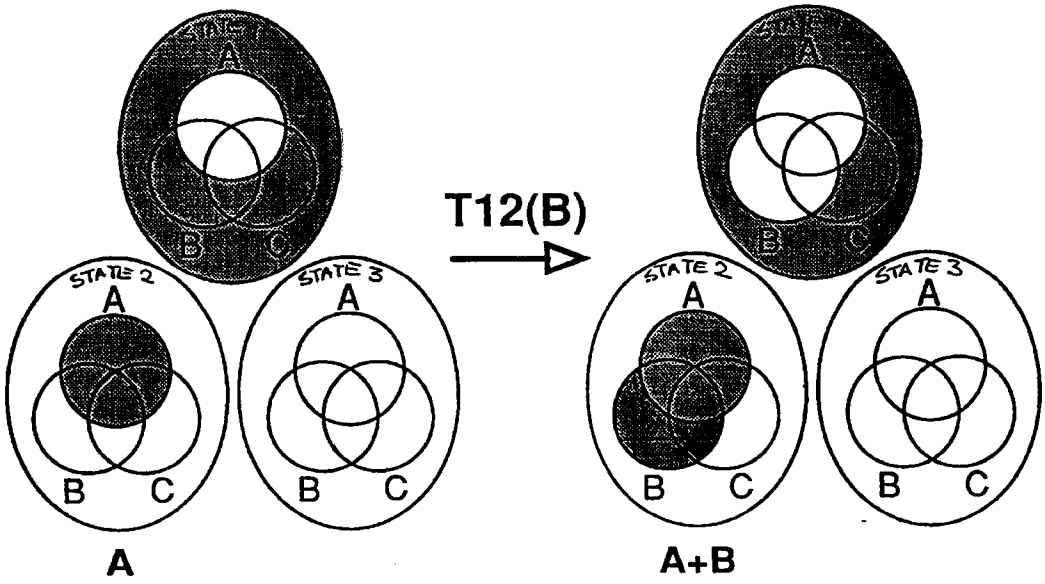
T12(B)
STATE 2
A
B C
STATE 3
A
B C
A
A+B

FIG. 15

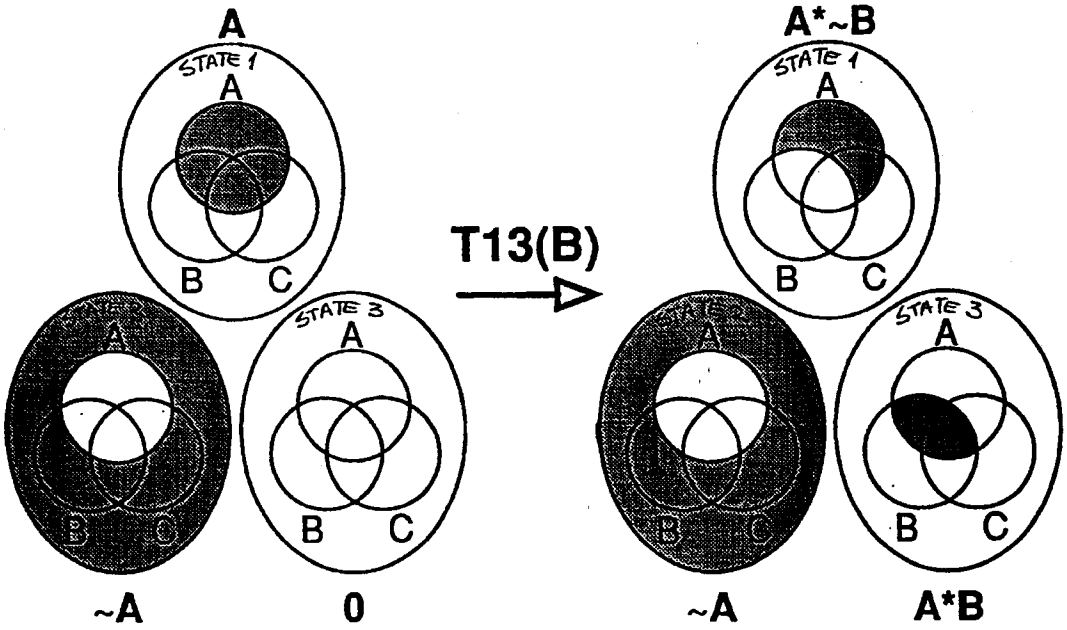
A
STATE 1
A
B C
STATE 3
A
B C
T13(B)
A*~B
STATE 1
A
B C
STATE 3
A
B C
~A
0
~A
A*B

FIG. 16

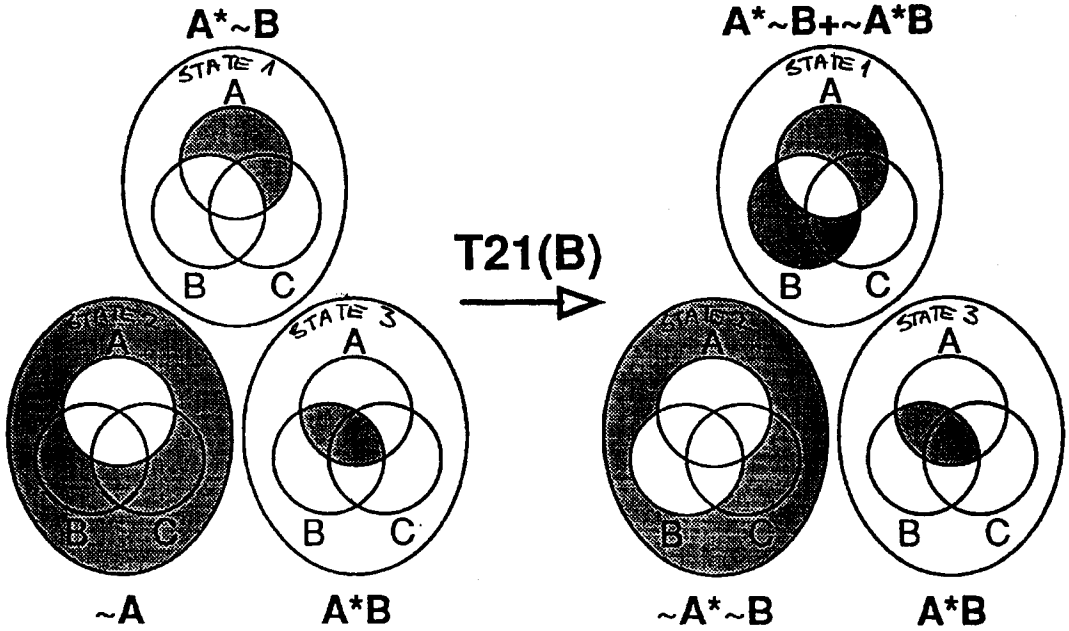
A*~B
STATE 1
A
B C
STATE 3
A
B C
T21(B)
A*~B+~A*B
STATE 1
A
B C
STATE 3
A
B C
~A
A*B
~A*~B
A*B

FIG. 17

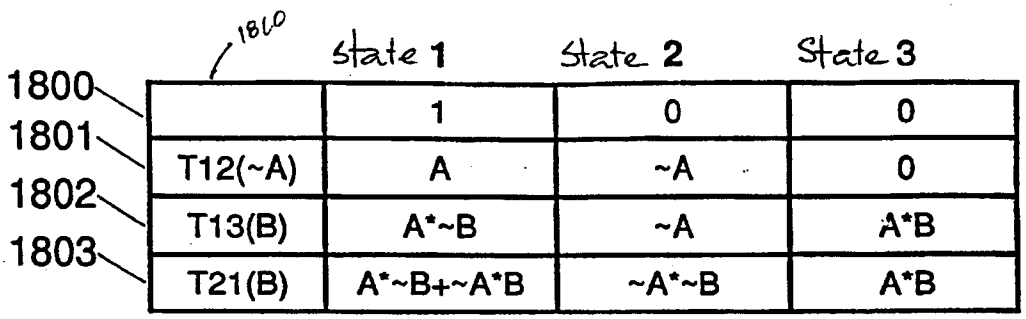

FIG. 18

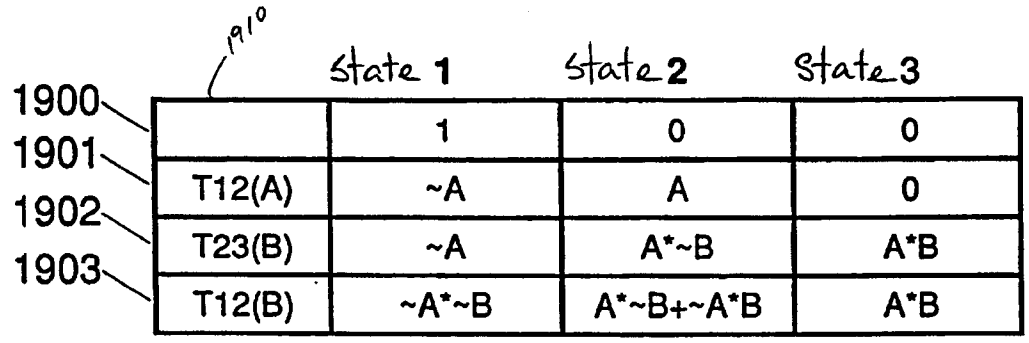

FIG. 19

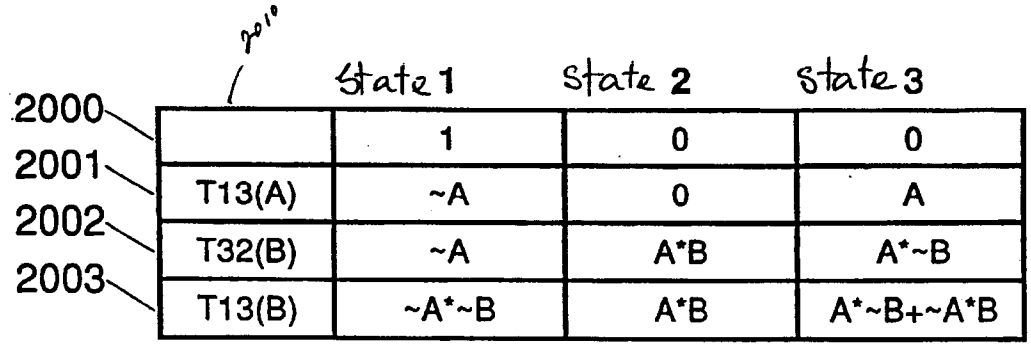

FIG. 20

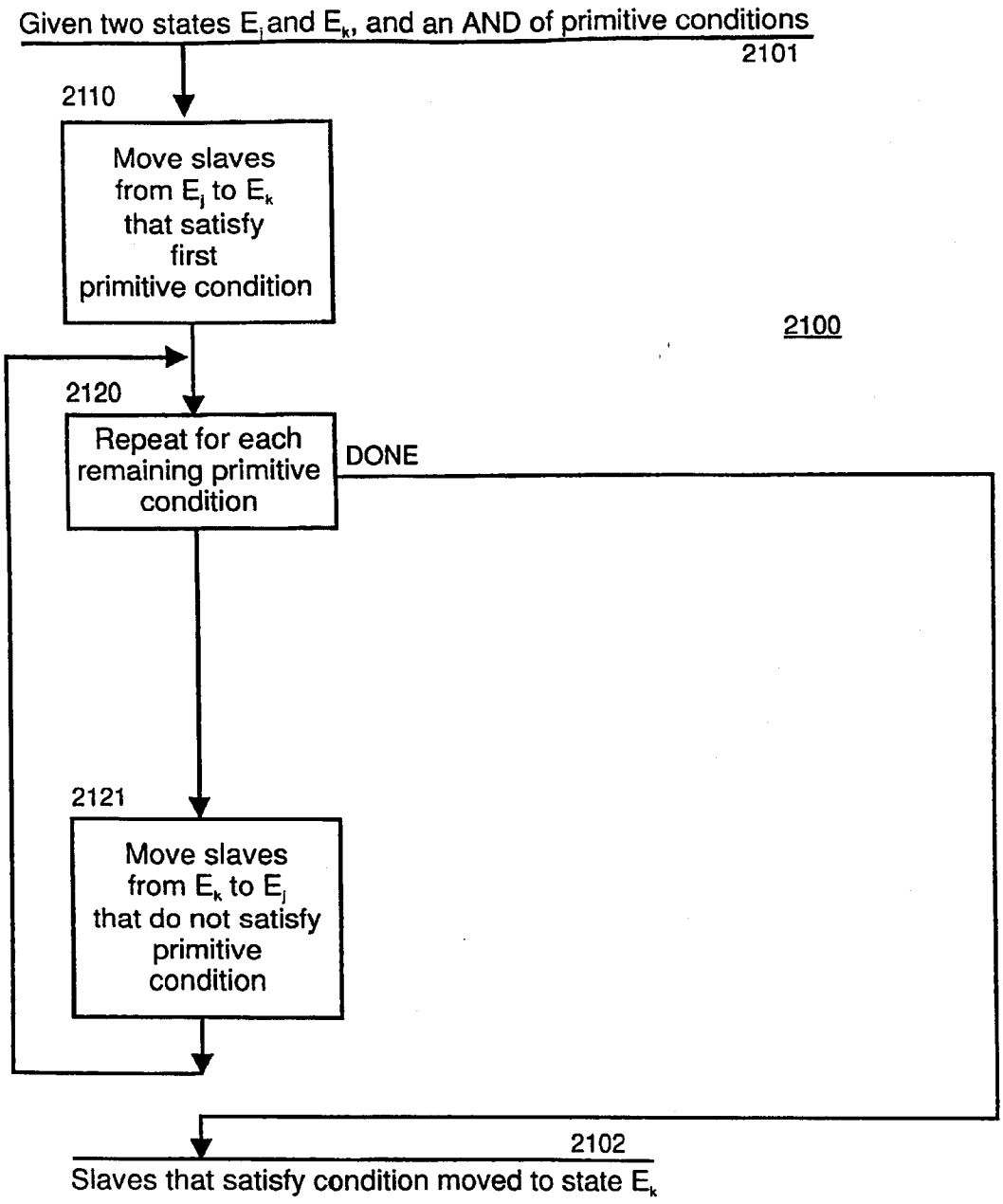
Given two states E_j and E_k, and an AND of primitive conditions
2101
2110
Move slaves from E_j to E_k that satisfy first primitive condition
2100
2120
Repeat for each remaining primitive condition
DONE
2121
Move slaves from E_k to E_j that do not satisfy primitive condition
2102
Slaves that satisfy condition moved to state E_k

FIG. 21

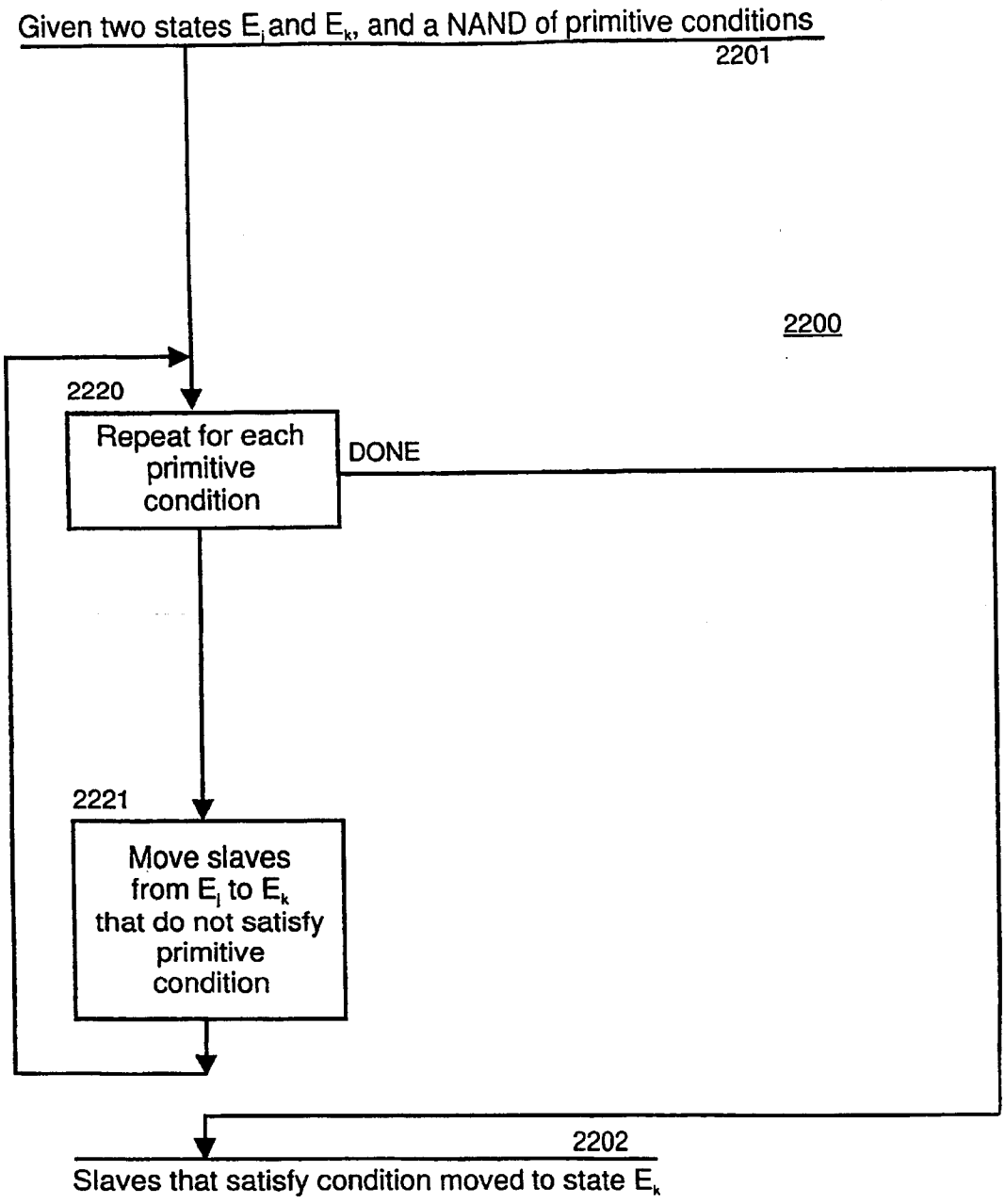
Given two states E_i and E_k, and a NAND of primitive conditions
2201
2200
2220
Repeat for each primitive condition
DONE
2221
Move slaves from E_i to E_k that do not satisfy primitive condition
2202
Slaves that satisfy condition moved to state E_k

FIG. 22

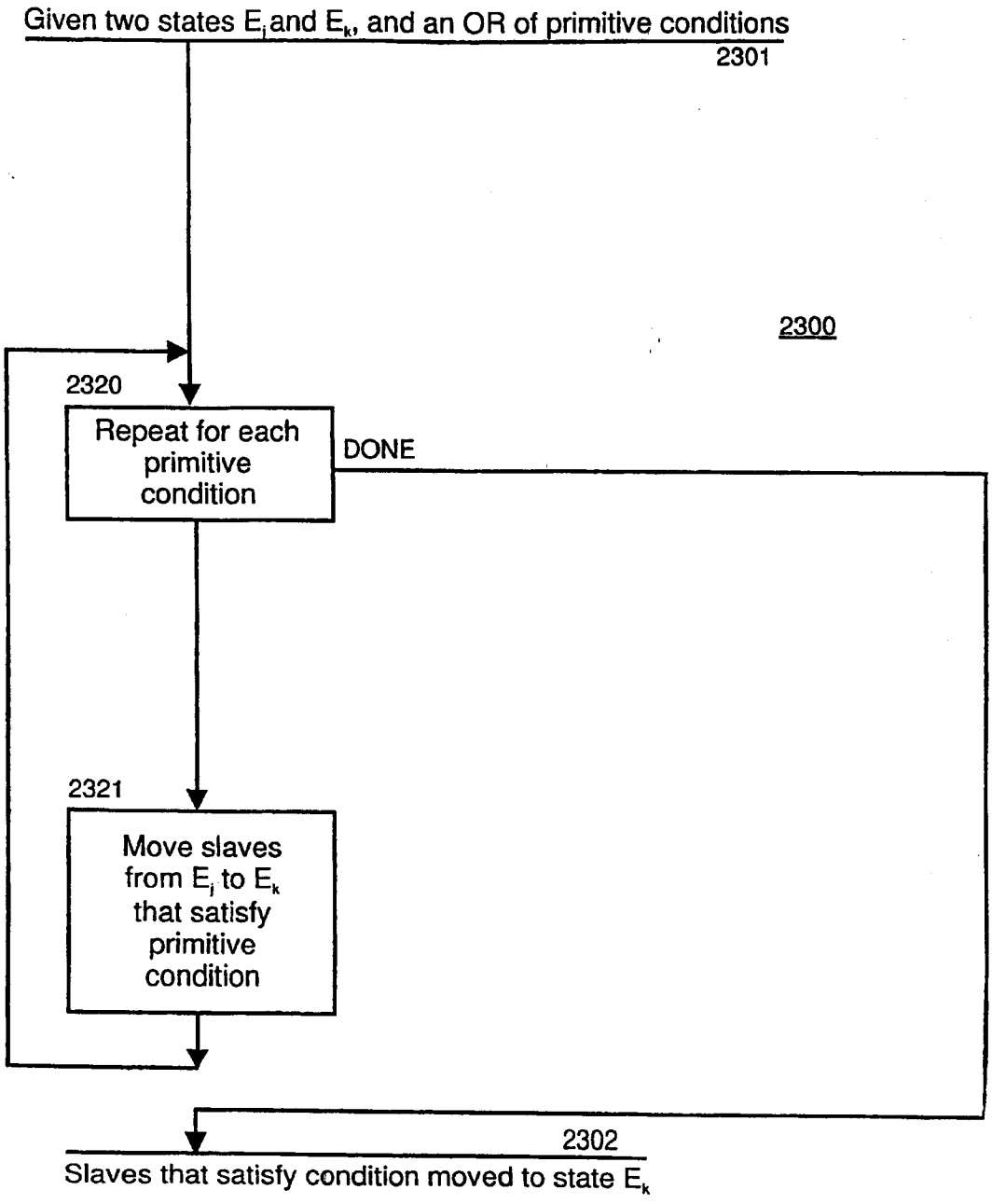
Given two states E_i and E_k, and an OR of primitive conditions
2301
2300
2320
Repeat for each primitive condition
DONE
2321
Move slaves from E_i to E_k that satisfy primitive condition
2302
Slaves that satisfy condition moved to state E_k

FIG. 23

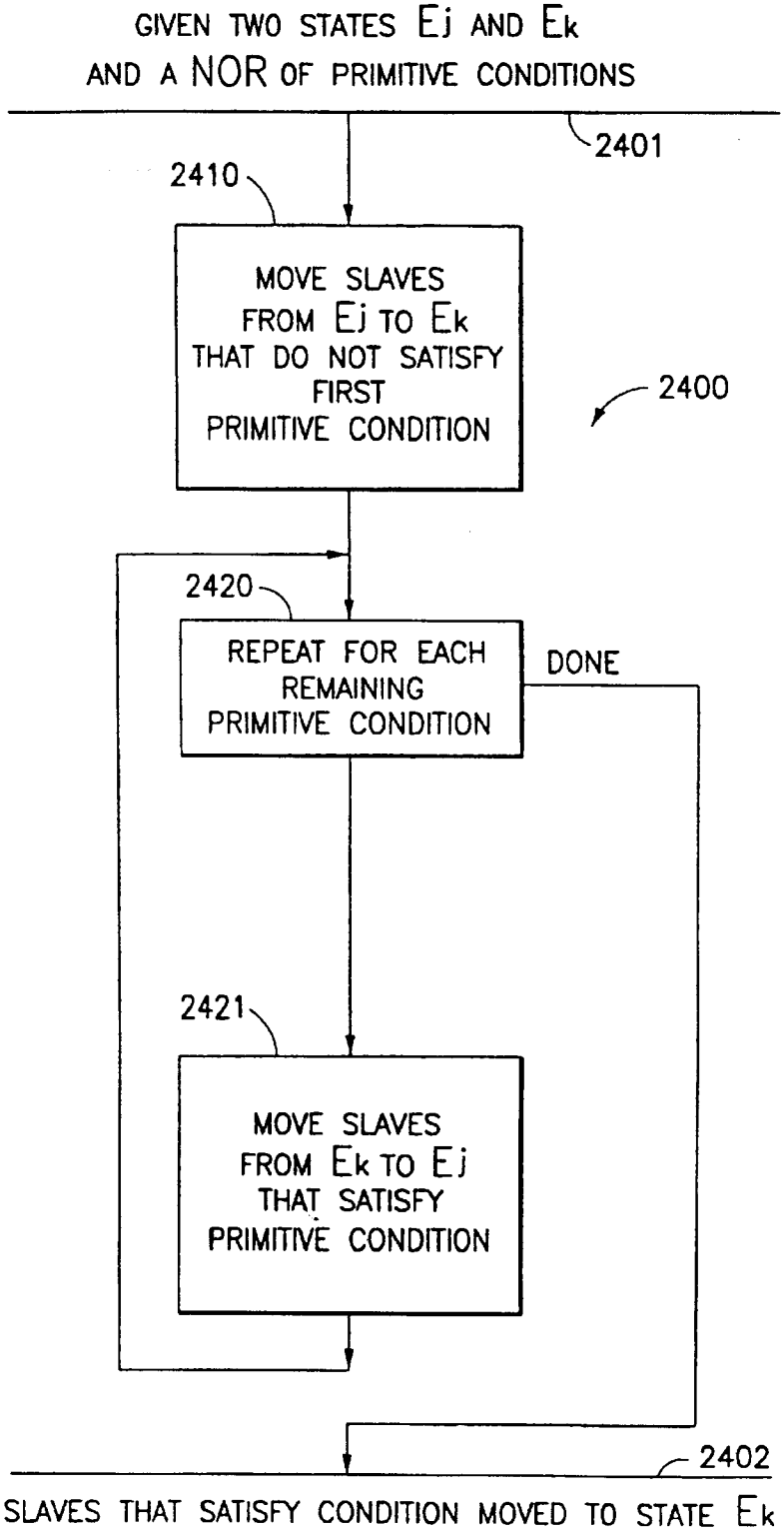
GIVEN TWO STATES Ej AND Ek
AND A NOR OF PRIMITIVE CONDITIONS
2401
2410
MOVE SLAVES FROM Ej TO Ek THAT DO NOT SATISFY FIRST PRIMITIVE CONDITION
2400
2420
REPEAT FOR EACH REMAINING PRIMITIVE CONDITION
DONE
2421
MOVE SLAVES FROM Ek TO Ej THAT SATISFY PRIMITIVE CONDITION
2402
SLAVES THAT SATISFY CONDITION MOVED TO STATE Ek

FIG. 24

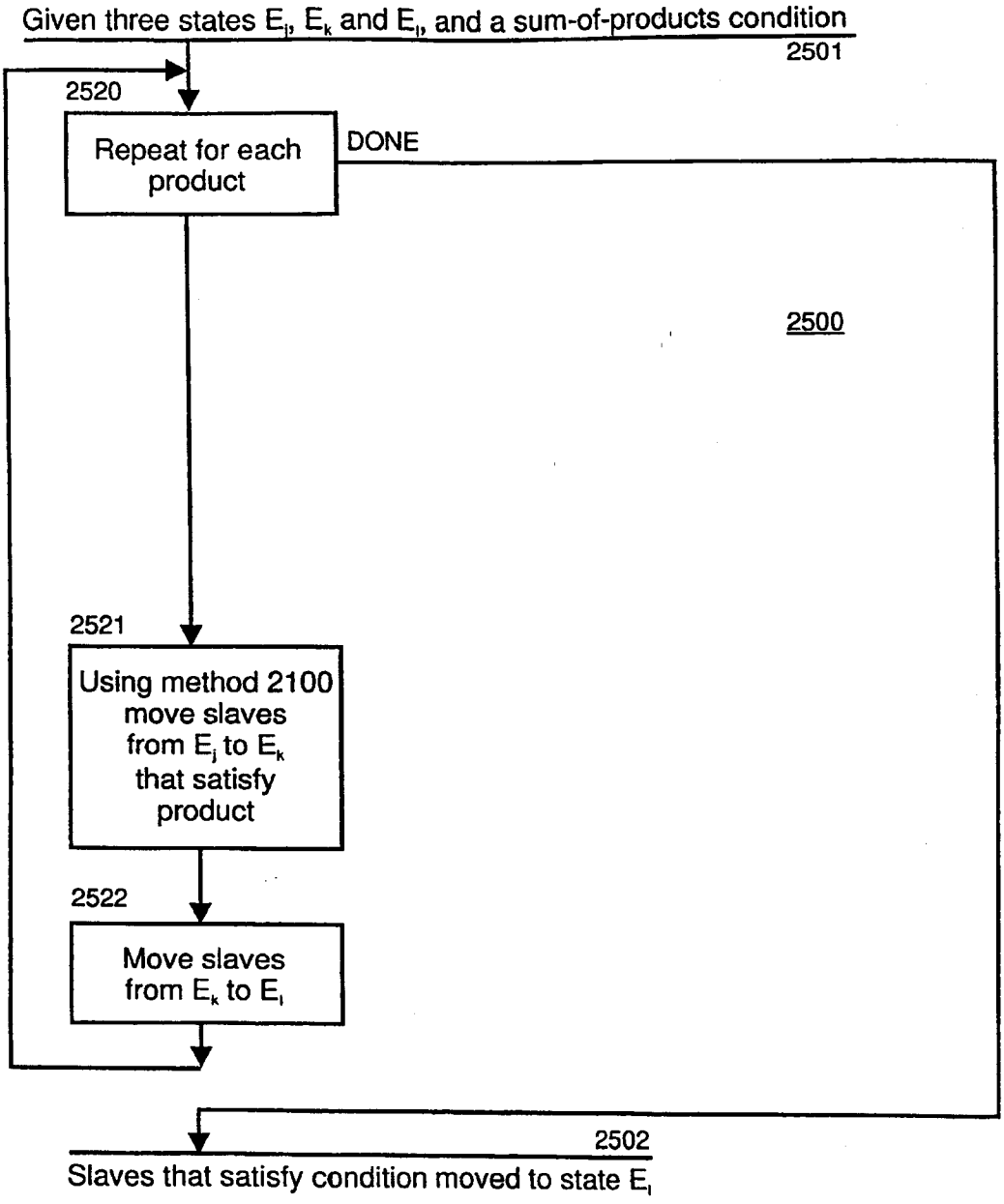
Given three states E_j, E_k and E_l, and a sum-of-products condition
2501
2520
Repeat for each product
DONE
2500
2521
Using method 2100 move slaves from E_j to E_k that satisfy product
2522
Move slaves from E_k to E_l
2502
Slaves that satisfy condition moved to state E_l

FIG. 25

	2610	STATE 1	STATE 2	STATE 3
2600		1	0	0
2601	T12(~A)	A	~A	0
2602	T21(~B)	A+~B	~A*B	0
2603	T23(1)	A+~B	0	~A*B
2604	T12(A)	~A*~B	A	~A*B
2605	T21(B)	~A*~B+A*B	A*~B	~A*B
2606	T23(1)	~A*~B+A*B	0	~A*B+A*~B

FIG. 26

	2710	STATE 1	STATE 2	STATE 3
2700		1	0	0
2701	T12(A)	~A	A	0
2702	T21(~C)	~A+~C	A*C	0
2703	T23(1)	~A+~C	0	A*C
2704	T12(B)	~A*~B+~B*~C	~A*B+B*~C	A*C
2705	T21(~C)	~A*~B+~C	~A*B*C	A*C
2706	T23(1)	~A*~B+~C	0	A*C+B*C

FIG. 27

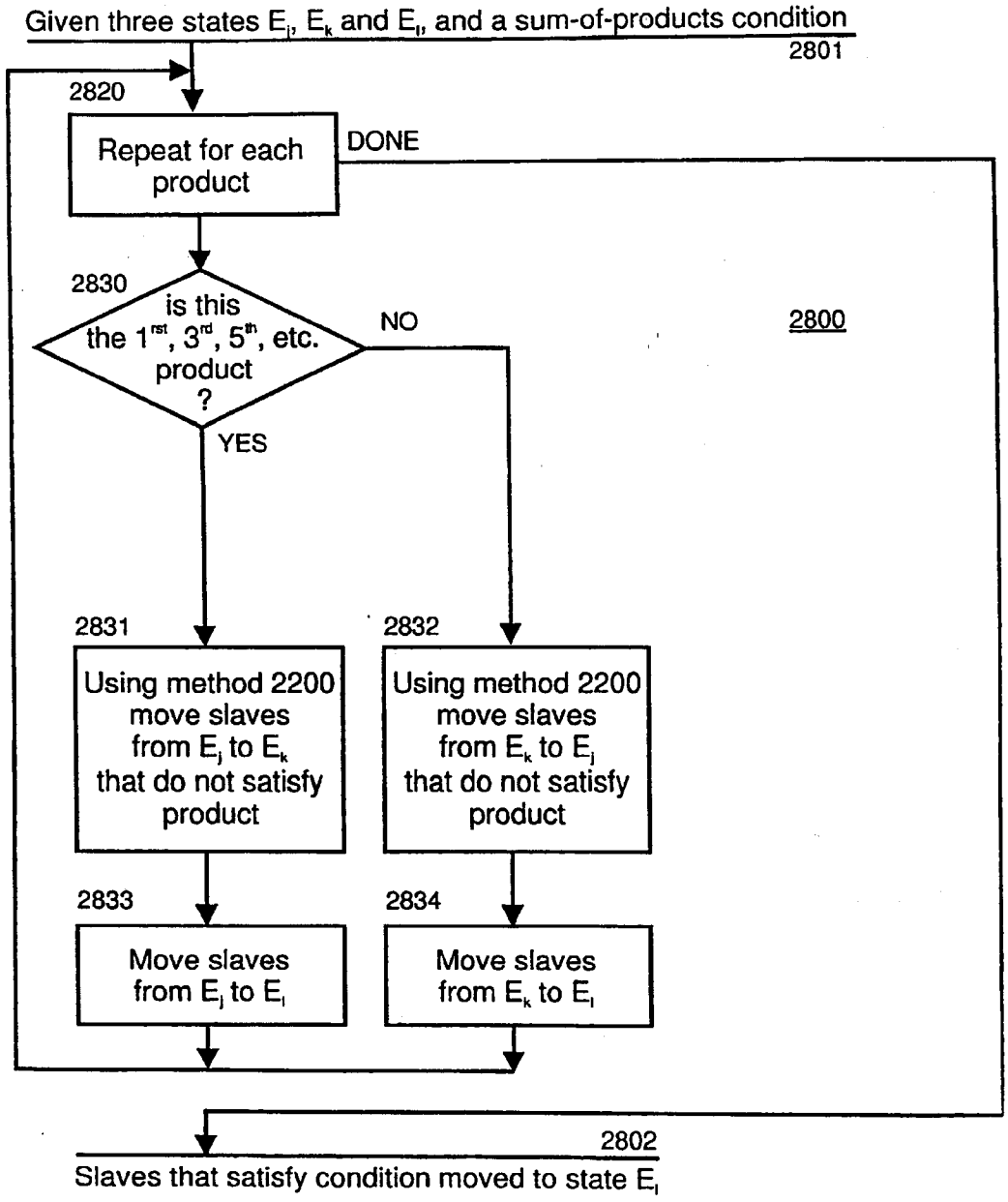
Given three states E_j, E_k and E_l, and a sum-of-products condition
2801
2820
Repeat for each product
DONE
2830
is this the 1st, 3rd, 5th, etc. product ?
NO
2800
YES
2831
Using method 2200 move slaves from E_j to E_k that do not satisfy product
2832
Using method 2200 move slaves from E_k to E_j that do not satisfy product
2833
Move slaves from E_j to E_l
2834
Move slaves from E_k to E_l
2802
Slaves that satisfy condition moved to state E_l

FIG. 28

		state 1	state 2	state 3
2900		1	0	0
2901	T12(A)	~A	A	0
2902	T12(~B)	~A*B	A+~B	0
2903	T13(1)	0	A+~B	~A*B
2904	T21(~A)	~A*~B	A	~A*B
2905	T21(B)	~A*~B+A*B	A*~B	~A*B
2906	T23(1)	~A*~B+A*B	0	~A*B+A*~B

FIG. 29

		state 1	state 2	state 3
3000		1	0	0
3001	T12(~A)	A	~A	0
3002	T12(~C)	A*C	~A+~C	0
3003	T23(1)	0	~A+~C	A*C
3004	T21(~B)	~A*~B+~B*~C	~A*B+B*~C	A*C
3005	T21(~C)	~A*~B+~C	~A*B*C	A*C
3006	T23(1)	~A*~B+~C	0	A*C+B*C

FIG. 30

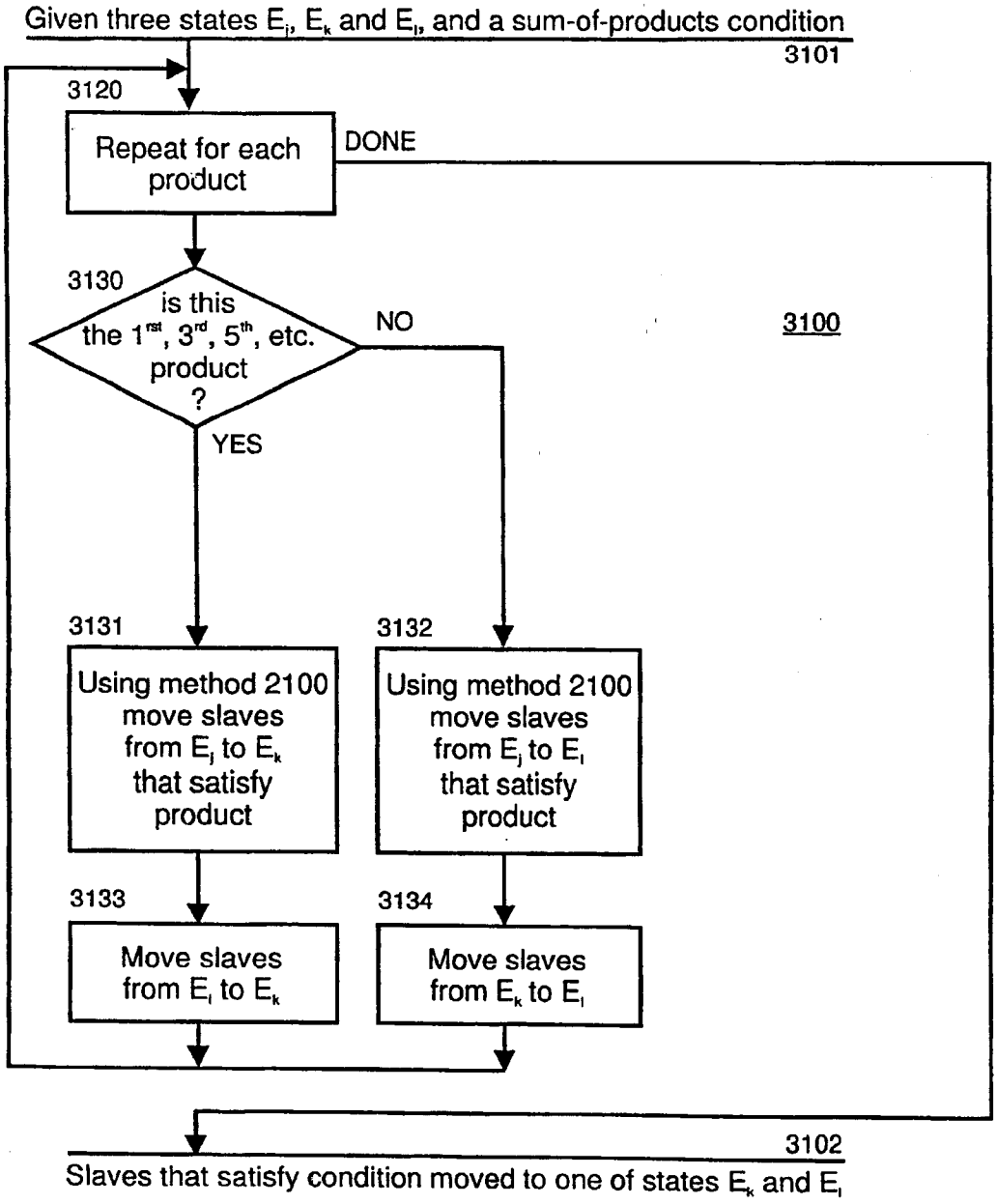
Given three states E_j, E_k and E_l, and a sum-of-products condition
3101
3120
Repeat for each product
DONE
3130
is this the 1st, 3rd, 5th, etc. product ?
NO
3100
YES
3131
Using method 2100 move slaves from E_j to E_k that satisfy product
3132
Using method 2100 move slaves from E_j to E_l that satisfy product
3133
Move slaves from E_l to E_k
3134
Move slaves from E_k to E_l
3102
Slaves that satisfy condition moved to one of states E_k and E_l

FIG. 31

3210

	state 1	state 2	state 3
3200	1	0	0
3201 T12(~A)	A	~A	0
3202 T21(~B)	A+~B	~A*B	0
3203 T32(1)	A+~B	~A*B	0
3204 T13(A)	~A*~B	~A*B	A
3205 T31(B)	~A*~B+A*B	~A*B	A*~B
3206 T23(1)	~A*~B+A*B	0	~A*B+A*~B

FIG. 32

3310

	state 1	state 2	state 3
3300	1	0	0
3301 T12(A)	~A	A	0
3302 T21(~C)	~A+~C	A*C	0
3303 T32(1)	~A+~C	A*C	0
3304 T13(B)	~A*~B+~B*~C	A*C	~A*B+B*~C
3305 T31(~C)	~A*~B+~C	A*C	~A*B*C
3306 T23(1)	~A*~B+~C	0	A*C+B*C

FIG. 33

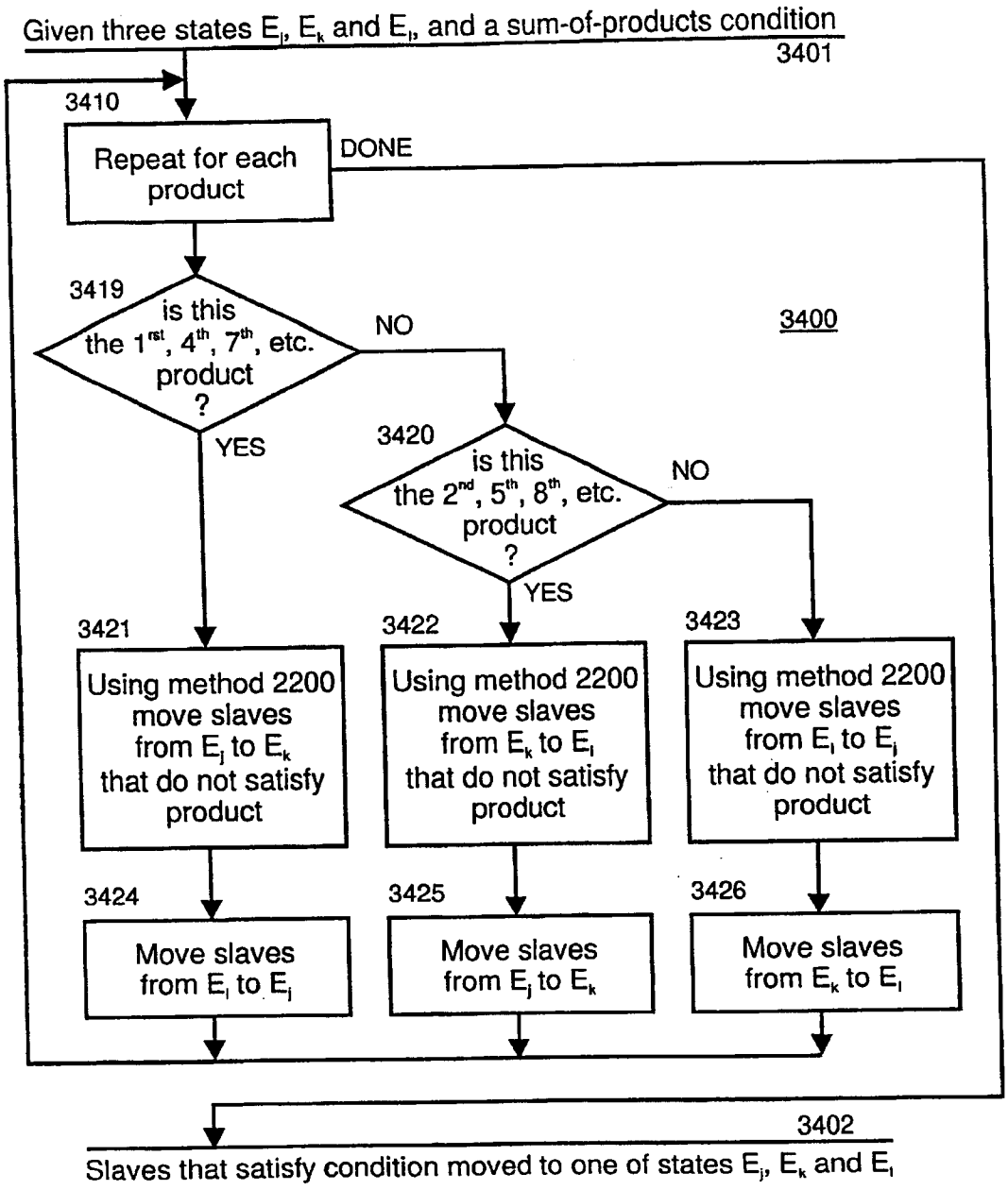
Given three states E_j, E_k and E_l, and a sum-of-products condition
3401
3410
Repeat for each product
DONE
3419
is this the 1st, 4th, 7th, etc. product ?
NO
3400
YES
3420
is this the 2nd, 5th, 8th, etc. product ?
NO
YES
3421
Using method 2200 move slaves from E_j to E_k that do not satisfy product
3422
Using method 2200 move slaves from E_k to E_l that do not satisfy product
3423
Using method 2200 move slaves from E_l to E_j that do not satisfy product
3424
Move slaves from E_l to E_j
3425
Move slaves from E_j to E_k
3426
Move slaves from E_k to E_l
3402
Slaves that satisfy condition moved to one of states E_j, E_k and E_l

FIG. 34

	state 1	state 2	state 3
3500	1	0	0
3501 T12(A)	~A	A	0
3502 T12(~B)	~A*B	A+~B	0
3503 T31(1)	~A*B	A+~B	0
3504 T23(~A)	~A*B	A	~A*~B
3505 T23(B)	~A*B	A*~B	~A*~B+A*B
3506 T12(1)	0	~A*B+A*~B	~A*~B+A*B

FIG. 35

	state 1	state 2	state 3
3600	1	0	0
3601 T12(~A)	A	~A	0
3602 T12(~C)	A*C	~A+~C	0
3603 T31(1)	A*C	~A+~C	0
3604 T23(~B)	A*C	~A*B+B*~C	~A*~B+~B*~C
3605 T23(~C)	A*C	~A*B*C	~A*~B+~C
3606 T12(1)	0	A*C+B*C	~A*~B+~C

FIG. 36

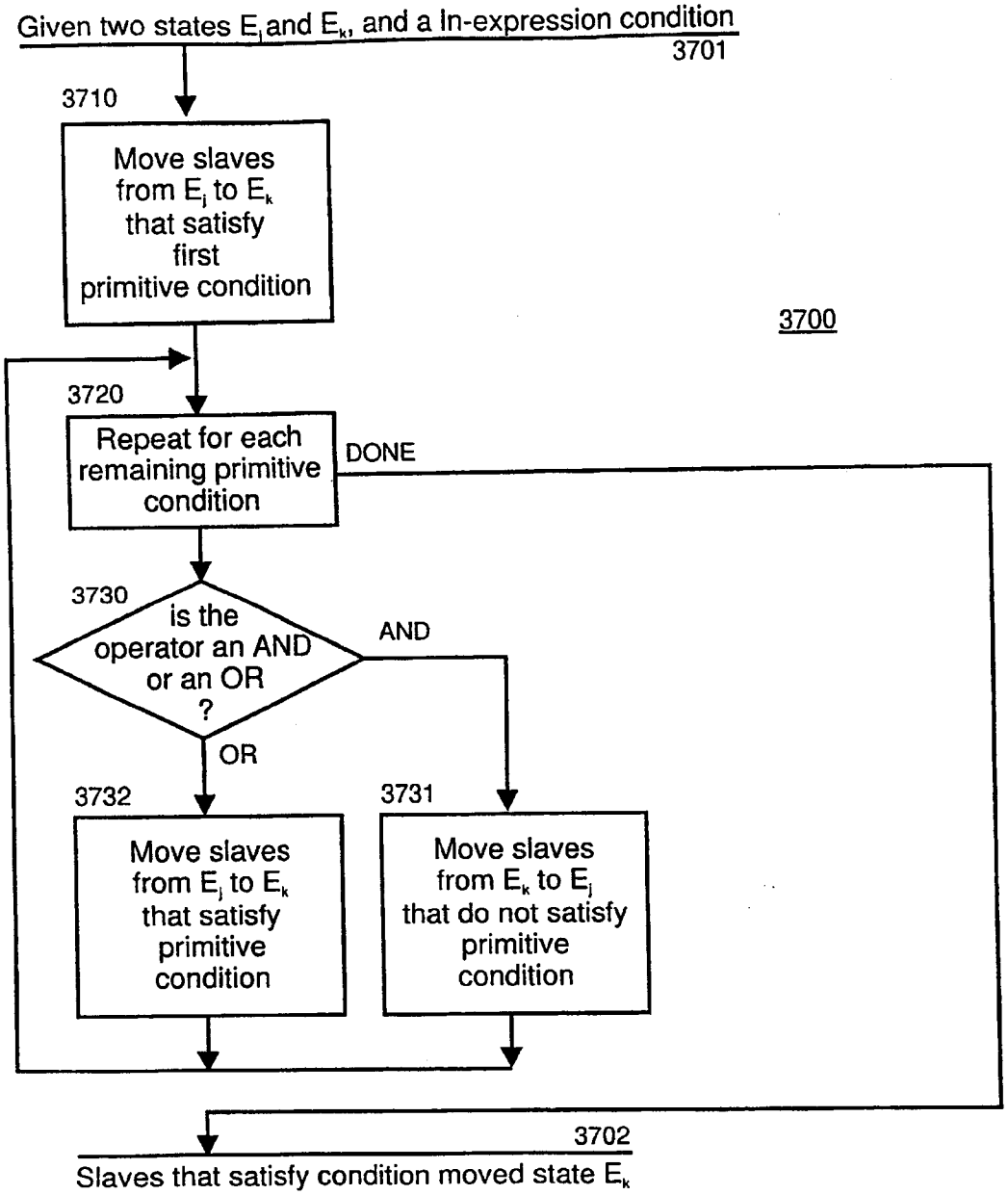
Given two states E_j and E_k, and a In-expression condition
3701
3710
Move slaves from E_j to E_k that satisfy first primitive condition
3700
3720
Repeat for each remaining primitive condition
DONE
3730
is the operator an AND or an OR ?
AND
OR
3732
Move slaves from E_j to E_k that satisfy primitive condition
3731
Move slaves from E_k to E_j that do not satisfy primitive condition
3702
Slaves that satisfy condition moved state E_k

FIG. 37

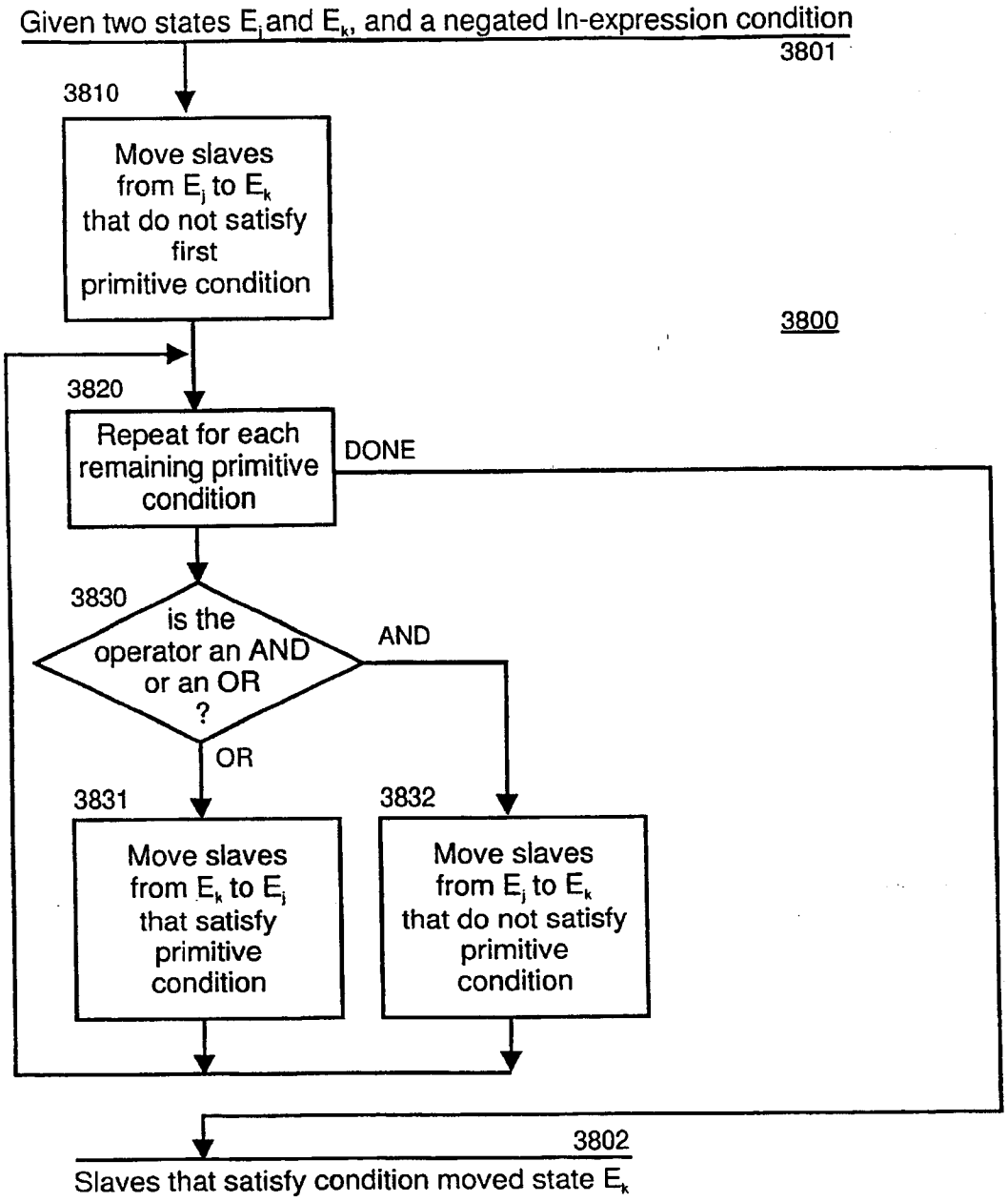
Given two states E_j and E_k, and a negated In-expression condition
3801
3810
Move slaves from E_j to E_k that do not satisfy first primitive condition
3800
3820
Repeat for each remaining primitive condition
DONE
3830
is the operator an AND or an OR ?
AND
OR
3831
Move slaves from E_k to E_j that satisfy primitive condition
3832
Move slaves from E_j to E_k that do not satisfy primitive condition
3802
Slaves that satisfy condition moved state E_k

FIG. 38

3910

	E1	E2	E3
3900	1	0	0
3901 T12(A)	~A	A	0
3902 T12(B)	~A*~B	A+B	0
3903 T21(~C)	~A*~B+~C	(A+B)*C	0

FIG. 39

4010

	E1	E2	E3
4000	1	0	0
4001 T12(~A)	A	~A	0
4002 T21(B)	A+B	~A*~B	0
4003 T12(~C)	(A+B)*C	~A*~B+~C	0

FIG. 40

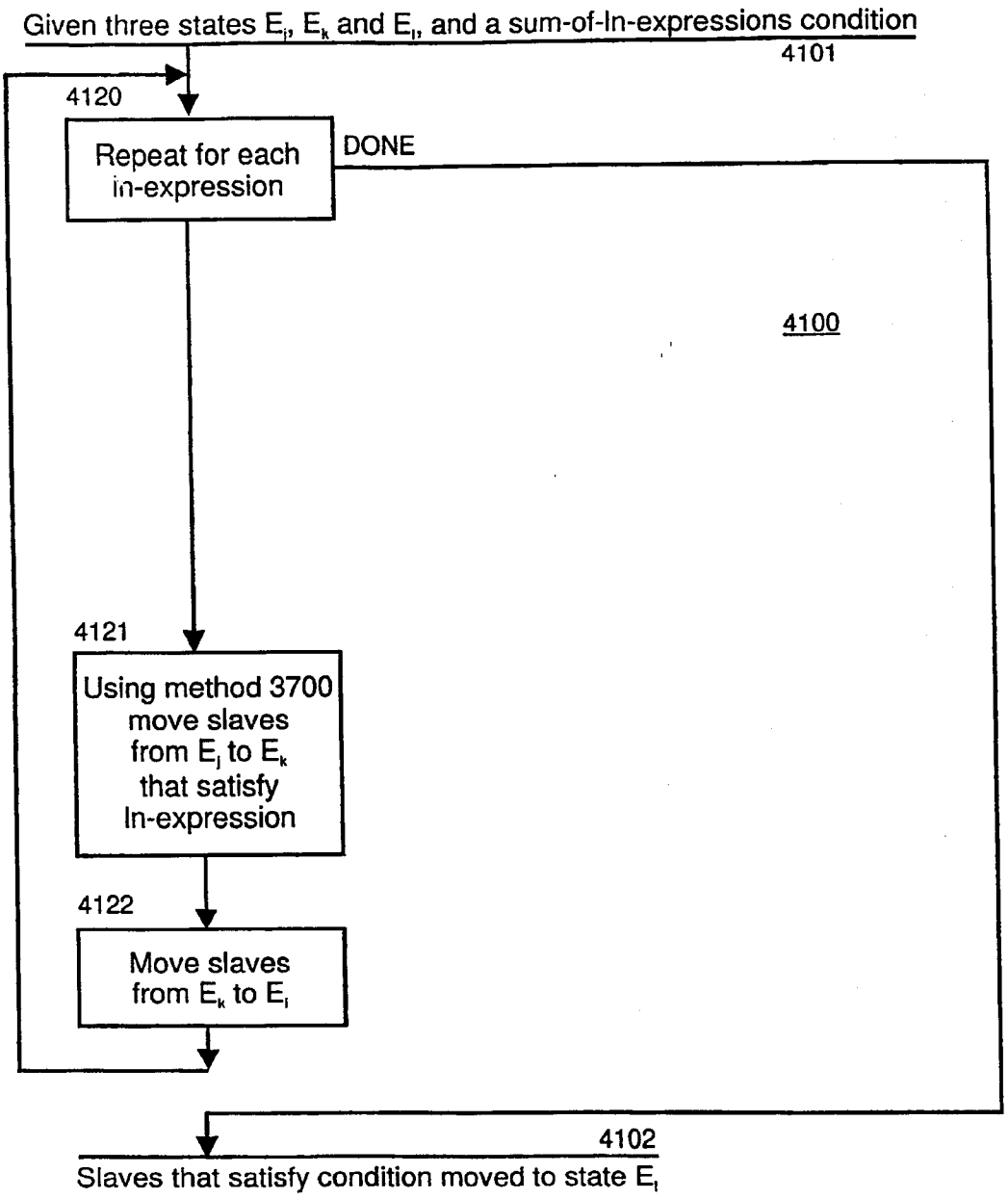
Given three states E_i, E_k and E_l, and a sum-of-ln-expressions condition
4101
4120
Repeat for each ln-expression
DONE
4100
4121
Using method 3700 move slaves from E_j to E_k that satisfy ln-expression
4122
Move slaves from E_k to E_l
4102
Slaves that satisfy condition moved to state E_l

FIG. 41

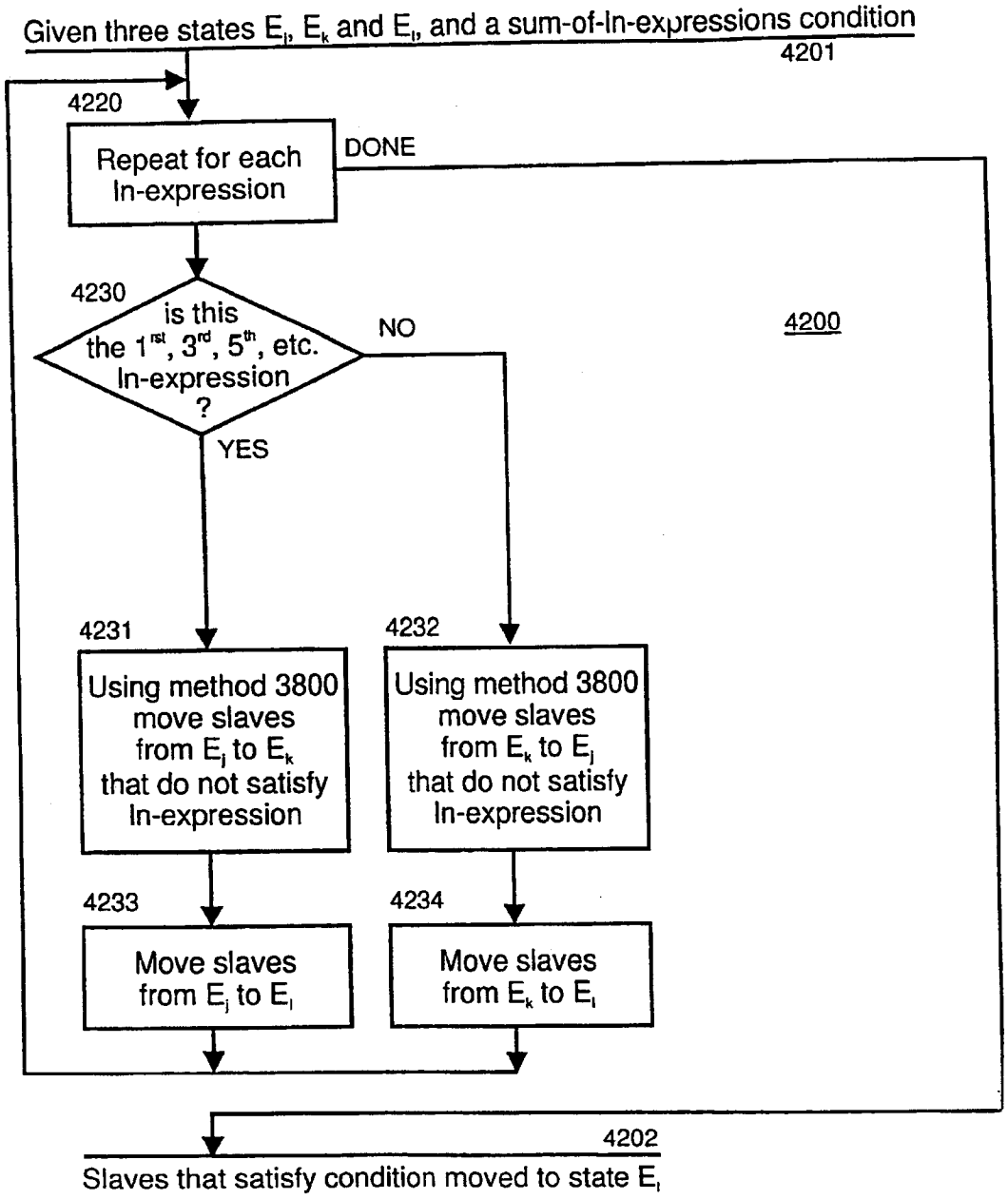
Given three states E_i, E_k and E_l, and a sum-of-ln-expressions condition
4201
4220
Repeat for each ln-expression
DONE
4230
is this the 1st, 3rd, 5th, etc. ln-expression ?
NO
YES
4200
4231
Using method 3800 move slaves from E_j to E_k that do not satisfy ln-expression
4232
Using method 3800 move slaves from E_k to E_j that do not satisfy ln-expression
4233
Move slaves from E_j to E_l
4234
Move slaves from E_k to E_l
4202
Slaves that satisfy condition moved to state E_l

FIG. 42

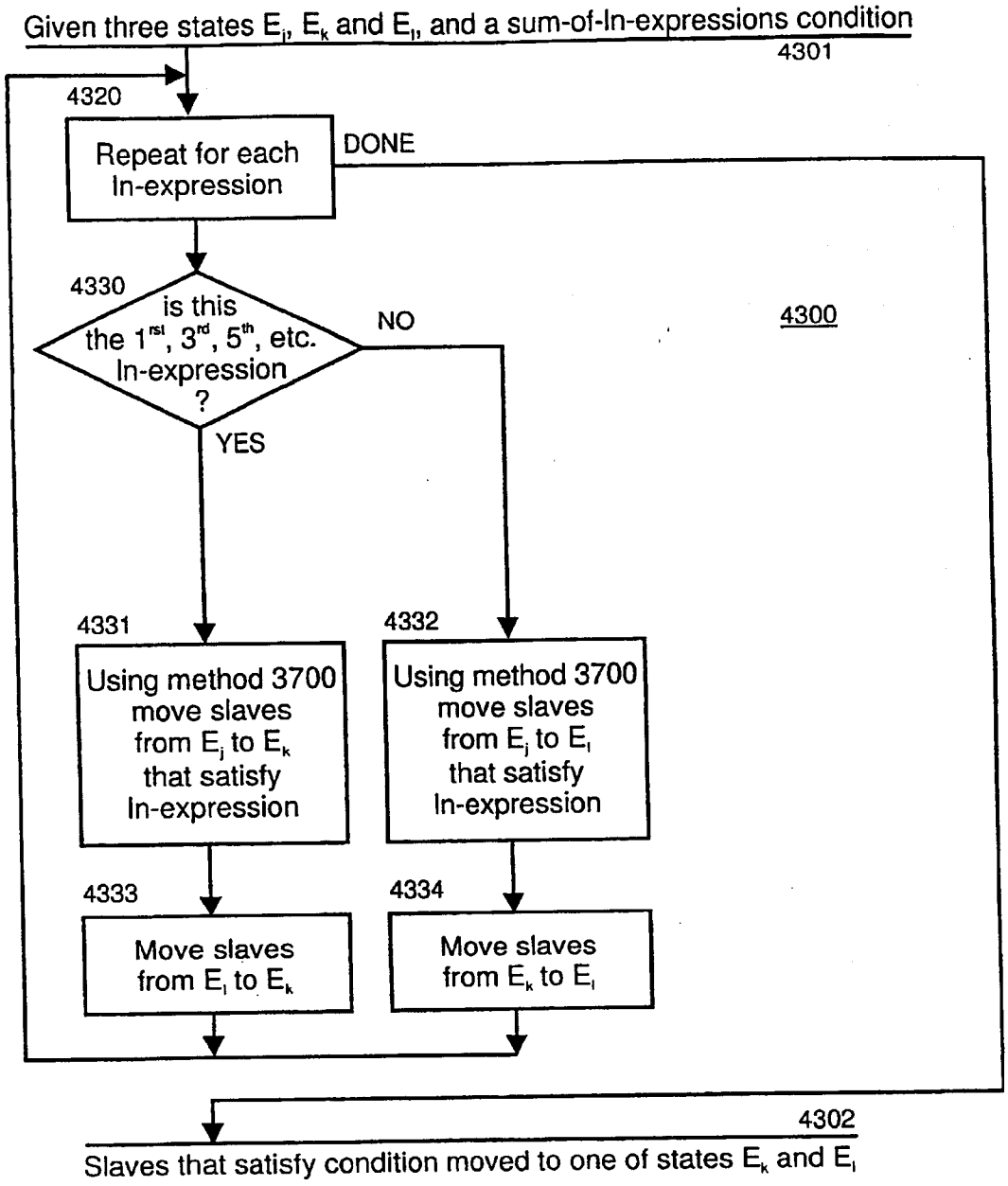
Given three states E_j, E_k and E_l, and a sum-of-ln-expressions condition
4301
4320
Repeat for each ln-expression
DONE
4330
is this the 1st, 3rd, 5th, etc. ln-expression ?
NO
4300
YES
4331
Using method 3700 move slaves from E_j to E_k that satisfy ln-expression
4332
Using method 3700 move slaves from E_j to E_l that satisfy ln-expression
4333
Move slaves from E_l to E_k
4334
Move slaves from E_k to E_l
4302
Slaves that satisfy condition moved to one of states E_k and E_l

FIG. 43

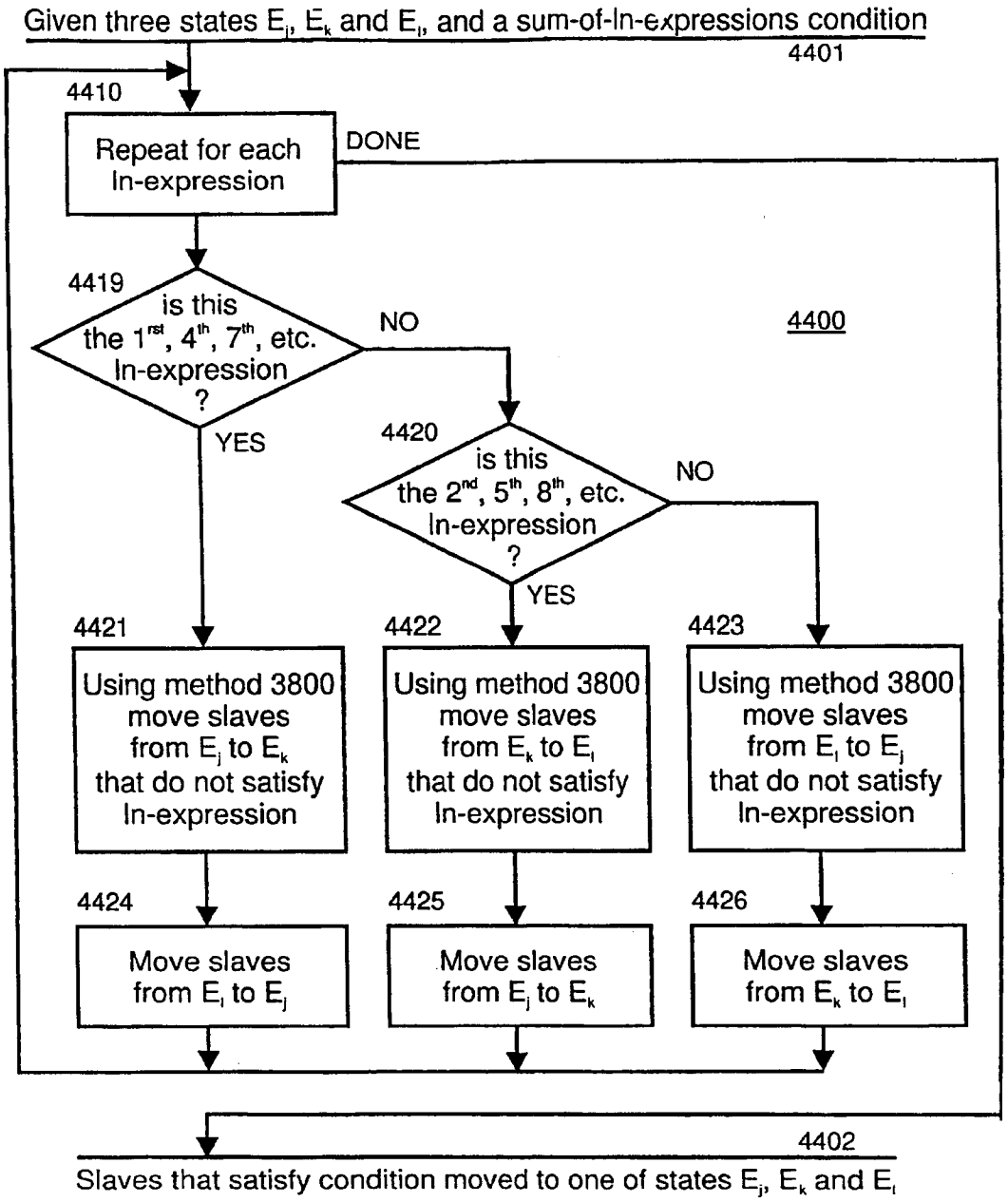
Given three states E_j, E_k and E_l, and a sum-of-In-expressions condition
4401
4410
Repeat for each In-expression
DONE
4419
is this the 1rst, 4th, 7th, etc. In-expression ?
NO
4400
YES
4420
is this the 2nd, 5th, 8th, etc. In-expression ?
NO
YES
4421
Using method 3800 move slaves from E_j to E_k that do not satisfy In-expression
4422
Using method 3800 move slaves from E_k to E_l that do not satisfy In-expression
4423
Using method 3800 move slaves from E_l to E_j that do not satisfy In-expression
4424
Move slaves from E_l to E_j
4425
Move slaves from E_j to E_k
4426
Move slaves from E_k to E_l
4402
Slaves that satisfy condition moved to one of states E_j, E_k and E_l

FIG. 44

SYSTEM AND METHOD FOR SELECTING A SUBSET OF AUTONOMOUS AND INDEPENDENT SLAVE ENTITIES

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of application Ser. No. 08/646,539 filed May 8, 1996, now U.S. Pat. No. 5,828,318 issued Oct. 27, 1998. The present application is also a continuation-in-part of application Ser. No. 08/694,606 filed Aug. 9, 1996, now U.S. Pat. No. 5,942,987 issued Aug. 24, 1999, which in turn is a continuation-in-part of application Ser. No. 08/303,965 filed Sep. 9, 1994, now U.S. Pat. No. 5,673,037 issued Sep. 30, 1997.

FIELD OF THE INVENTION

The invention relates to communications between a master station and one or more slave stations. More specifically, the invention relates to a master station selecting subset(s) of the slave stations by broadcasting commands with conditions that the selected slaves meet.

BACKGROUND OF THE INVENTION

In the prior art, a master control unit is to communicate with a plurality of autonomous and independent slaves. In such environment, the number of slaves is often not known a priori. There may in fact be no slaves with which the master can communicate. Among the reasons the master may have to communicate with the slaves are (a) the need to acknowledge their presence, (b) identify and count them and/or (c) order them to perform tasks. This kind of computational environment falls under the broad category of broadcasting sequential processes, which is defined by Narain Gehani in Chapter 9 of the book co-edited with Andrew McGettrick, "Concurrent Programming" (Addison-Wesley, 1988), which is herein incorporated by reference in its entirety.

Because the master often does not know ahead of time the number of slaves present and because that number may be very large and possibly unyieldy, it is advantageous for the master to be able to select a subset of the slaves with whom to communicate further. Such a selection must of course be done by a conditional. Those slaves that meet the condition are thus considered selected, while those that do not meet the condition are considered not selected. The selection is performed by broadcasting to all slaves the condition that must be met. This is akin to asking those among a large crowd of people whose last name is Lowell to raise their hand. Each slave is defined has having at least the capability to listen to the master's broadcasts, to receive the broadcast condition and to self-test so as to determine whether it meets the condition. See for example, U.S. patent application Ser. No. 08/303,965, entitled "Radio Frequency (RF) Group Select Protocol" to Cesar et al. filed on Sep. 9, 1994 which is herein incorporated by reference in its entirety.

Practical environments where this computational model can be applied include bus arbitration, wireless communication, distributed and parallel processing. Characteristic of such environments is the existence of a protocol for how master and slaves communicate. The aforementioned capability of subset selection can be an important additional component of that protocol.

Finite state-machines are a well-known modelling tool. The set theory that often accompanies the definition of finite state-machines is also well known. Both subjects are amply covered in any of many books on discrete or finite mathematics that are available today. The book by Ralph Grimaldi, "Discrete and Combinatorial Mathematics: An Applied Introduction" (Addison-Wesley, 1985), is a fine example of its kind.

STATEMENT OF PROBLEMS WITH THE PRIOR ART

In the prior art, the methods used for selecting subsets of slaves is limited to comparisons against the information held by the slaves such that the comparison is either true or false and the slaves can be in either of two selection states: selected or not selected. The slave may contain many other states, but only two are effectively dedicated to the purpose of subset selection.

In some older prior art, a comparison will override a previous comparison. There is no notion of accumulating and combining successive comparisons to effect a selection according to a complex condition.

More recent prior art allows slaves to move between two selection states according to successive comparisons. That allows some complex conditions to be effected. However not all complex conditions can be effected with such two-selection-state machine. For example, the complex condition "is-red and is-not tall or is-not-red and is-tall", that is, the EXCLUSIVE-OR of the two simple comparisons "is-red" and "is-tall", can not be performed such that the subset of slaves that satisfy the EXCLUSIVE-OR are in the first state and those that do not satisfy the EXCLUSIVE-OR are in the second state. In the case of complex conditions involving two comparisons and their negation, the two-selection-state machine can not perform the EXCLUSIVE-OR and the EQUIVALENCE logical operators. In the case of complex conditions involving more than two comparisons and their negation, the two-selection-state machine can not perform an increasingly large number of logical equations.

In the prior art, conditions such as the EXCLUSIVE-OR must be broken up into two independent processing steps. First, slaves satisfying the first AND term are selected and all necessary processing sequence is performed over them. Second, after a general reset, slaves satisfying the second AND term are selected and the same necessary processing sequence is repeated over those. That means that the processing sequence must be broadcast twice. In the case of more complicated conditions, rebroadcasting of such sequence may happen more than twice. For example, the condition (A*~B*~C)+(~A*B*~C)+(~A*~B+C) would need three rebroadcasts.

The only conditions that can be executed in a single round of broadcasting by a two-selection-state logic as used by the prior art are those conditions that can be expressed by a left-nested expressions, such as ((A+B+C)*D*E)+F). OR conditions, such as (A+B+C+D), and AND conditions, such as (A*B*C), are particular cases of left-nested expressions. In contrast, EXCLUSIVE-OR type conditions, such as (A*B*~C)+(A*~B*C)*(~A*B*C), can not be written as left-nested expressions and therefore can not be handled by the two-selection-state logic.

Among the prior art is U.S. Pat. No. 5,434,572, entitled "System and Method for Initiating Communications between a Controller and a Selected Subset of Multiple Transponders in a Common RF Field" to Smith dated Jul. 18, 1995. The method begins by selecting all "transponders" in a field and, by a sequence of commands, incrementally moving groups of slaves to a "reset" condition.

In the U.S. Pat. No. 5,410,315, entitled "Group-Addressable Transponder Arrangement" to Huber dated Apr. 25, 1995, a selection is essentially made through a comparison against a "group and/or unit address". Unlike Smith, there is no progressive incremental refinement. Huber can perform only limited AND operations.

OBJECTS OF THE INVENTION

An object of this invention is a system and method for using arbitrarily complex logical conditions to select slave stations that satisfy those conditions transmitted by a master station through a series one or more commands.

An object of this invention is a system and method for using arbitrarily complex logical conditions to select RF transponders that satisfy those conditions transmitted by a base station through a series one or more commands.

SUMMARY OF THE INVENTION

The present invention is a system and method for selecting a subset of a plurality of autonomous and independent slaves, wherein each slave comprises (i) a three-state machine dedicated to selection, (ii) some other stored information, and (iii) a logic to execute externally provided commands in a command sequence that exercise the three-state machine. The primary purpose of the commands is to effect state transitions. The slave receives the command, which causes a comparison to be performed against the slave's stored information, the results of which possibly causing a state transition in the slave.

The commands, in a sequence called a command sequence, are broadcast from at least one master control unit to zero or more slaves. The exact number of slaves may not be known by the master. The master executes a method by which a sequence of discrete commands is broadcast to all slaves. The overall purpose of the method is to bring a subset of the slaves to be at the same state of their three-state machine, while all other slaves are at any one of the two other remaining states.

A three-state machine dedicated to selection is present in every slave. Each slave is at one of those three states, therefore, at any one time, the slaves can be subdivided into three subsets: those slaves that have their selection three-state machine at the first state, those at the second state, and those at the third state. In a preferred embodiment, transitions are possible between any two states of the three-state machine. Transitions are requested by command (sequence) broadcast from the master. A command specifies a desired transition, say from the second state to the first state. Only slaves that are at the second state may be affected. The command also specifies a condition under which the transition will occur. If the condition is met, the transition is effected; if not, the slave remains in its previous state.

In a preferred embodiment, slaves can be moved from a first state to a second state and visa versa. Only slaves in the second state can be moved to a third state. The slaves in the third state ignore the remaining commands in the command sequence. In alternative preferred embodiments, the first and second states reverse roles after an end of one or more subsequences in the sequences of commands. Also, the second and third states can reverse roles after an end of one or more subsequences. Further, the states of the slaves can cycle their roles at the end of one or more of the subsequences.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of preferred embodiments of the invention with reference to the drawings that are included:

FIG. **1** is a block diagram of a master control unit broadcasting commands to a plurality of slaves.

FIG. **2** is a block diagram of the components of a master control unit.

FIG. **3** is a block diagram of the components of a slave.

FIG. **4** shows a state diagram showing a three-state machine that allows all six possible transitions between any two different states.

FIG. **5** shows a state diagram showing a three-state machine that allows five possible transitions between any two different states.

FIG. **6** shows a state diagram showing a three-state machine that allows four possible transitions between any two different states, such that any state is reachable from any other state.

FIG. **7** shows a state diagram showing a three-state machine that allows four possible transitions between any two different states, such that any state is reachable from any other state and two of the states have no transitions between them.

FIG. **8** shows a state diagram showing a three-state machine that allows three possible transitions between any two different states, such that any state is reachable from any other state.

FIG. **9** lists all possible three-state machines that can be used for the purposes of this invention.

FIG. **10** is a set theoretic representation of how the plurality of slaves is subdivided into at most three sets.

FIG. **11** describes what happens when a command to transfer slaves that satisfy some condition from one state to another is broadcast.

FIGS. **12, 13, 14, 15, 16** and **17** exemplifies by means of Venn diagrams how a command transfers elements from one set to another.

FIGS. **18, 19** and **20** show sequences of commands for selecting a subset of slaves that satisfy an EXCLUSIVE-OR condition and such that those slaves end up in a first, second and third set, respectively.

FIG. **21** describes a method that computes a product (AND) condition.

FIG. **22** describes a method that computes a negated product (NAND) condition.

FIG. **23** describes a method that computes a sum (OR) condition.

FIG. **24** describes a method that computes a negated sum (NOR) condition.

FIG. **25** describes a method that computes a condition written in sum-of-products form whereby the product terms are built in a second state and the sum is accumulated in a third state.

FIGS. **26** and **27** exemplify the use of the method described in FIG. **25**.

FIG. **28** describes a method that computes a condition written in sum-of-products form whereby the product terms are built alternatively in a first and second states and the sum is accumulated in a third state.

FIGS. **29** and **30** exemplify the use of the method described in FIG. **28**.

FIG. **31** describes a method that computes a condition written in sum-of-products form whereby the product terms are built alternatively in a second and third states and the sum is accumulated in that second and third state, respectively.

FIGS. **32** and **33** exemplify the use of the method described in FIG. **31**.

FIG. **34** describes a method that computes a condition written in sum-of-products form whereby the product terms are built alternatively in a first, second and third states and the sum is accumulated in that first, second and third state, respectively.

FIGS. **35** and **36** exemplify the use of the method described in FIG. **31**.

FIG. **37** describes a method that computes a single left-nested expression using only two states.

FIG. **38** describes a method that computes the negation of a single left-nested expression using only two states.

FIG. **39** exemplifies the use of the method described in FIG. **37**.

FIG. **40** exemplifies the use of the method described in FIG. **38**.

FIG. **41** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built in a second state and the sum is accumulated in a third state.

FIG. **42** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built alternatively in a first and second states and the sum is accumulated in a third state.

FIG. **43** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built alternatively in a second and third states and the sum is accumulated in that second and third states, respectively.

FIG. **44** describes a method that computes a condition written in sum-of-left-nested-expressions form whereby the left-nested expressions are built in a first, second and third states and the sum is accumulated in that first, second and third states, respectively.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** shows least one master control unit **101** communicating with a plurality of autonomous and independent slaves **102**. The communication medium **103** can be in terms of either direct electric contact means or electromagnetic radiation means, e.g., radio frequency (RF) embodiments. However, it also encompasses light, sound and other frequencies utilized for signalling purposes. Master unit **101** is capable of broadcasting commands at the plurality of slaves **102** via communication medium **103**. Each slave is capable of receiving the broadcast commands which are processed by logic **150**. For example, U.S. Pat. No. 4,656,463 to Anders et al. shows an RF tag systems where for our purposes the active transceiver (AT) would be the master control unit **101**, the passive transceivers (PT) would be the independent slaves **102**, and the communication medium **103** would be RF over free space. In an alternative preferred embodiment, U.S. Pat. No. 5,371,852 to Attanasio et al. shows a cluster of computers where for our purposes the gateway would be the master unit **101**, the nodes in the cluster would be the slaves **102**, and the communication medium **103** would be the interconnect. These references are incorporated by the reference in their entirety.

FIG. **2** shows that a master unit **200** comprises (a) means **201** for broadcasting commands from a command set **250** to a plurality of slaves, and (b) processing means **202** for determining the correct sequence of commands to be broadcast. In one embodiment, processing means **202** are proximate to broadcast means **201**. Other embodiments are possible where processing means **202** and broadcast means **201** are remote from each other.

FIG. **3** shows that a slave **300** comprises (a) a receiver **301** for receiving commands from a master, (b) a three-state machine **304**, (c) a memory with stored information **303** (d) processor or logic **302** for executing any received command, performing any condition testing over the stored information **303** as specified by the command, and effecting a state transition on three-state machine **304** conditional to the result of the condition testing. Receiving means **301** and broadcasting means **201** must by necessity be compatible. The receiving means **301** are well known. For example in RF tagging, radio frequency receivers/transmitters are used. In the networking arts standard connections to networks and/or information buses are used. Stored information **303** is typically embodied in the form of registers and/or memory.

The three-state machine **304** comprises a select state, a first unselect state, and a second unselect state state. All three of these states can be used in the selection and unselection of sets of slaves. The logic **302** is further described below.

The significant difference between a two and a three-selection-state machine is that, using any sequence of commands, the former can only isolate or select slaves that satisfy a condition expressed by a left-nested expression. Using a two-selection-state machine, there is no sequence of commands that can process conditions that are expressed as as a SUM-of-left-nested-expressions.

Only a three-selection-state machine can select slaves that satisfy a condition expressed by a sum-of-left-nested-expression. Further, a three-selection-state machine is also sufficient to select a set of slaves that satisfy any arbitrary condition, even though those conditions are expressed by a sum-of-left-nested-expression. Therefore adding a fourth, fifth, etc. state does not add any new capability to the selection logic. In addition, since any condition can be expressed by a sum-of-left-nested expression, a three-selection-state machine can select a set of slave satisfying any possible condition. This capability is undisclosed and unrecognized in the prior art.

The invention enables this capability because a separate condition (or set of conditions), each corresponding to a set of slaves, can be isolated in any one of the three states at any given time. Therefore, operations on two sets of conditions, in two of the respective states, can be performed without affecting or being affected by the conditions held in the third state.

In one embodiment, receiving means **301**, processing means **302**, stored information **303**, and three-state machine **304** are proximate. Other embodiments are possible where the components **301**, **302**, **303** and **304** are remote from each other, in part or completely.

The three states are dedicated to the process of determining whether a slave satisfies an arbitrarily complex condition. During the process of determining whether the slave satisfies the condition, the slave may be in any of the three states as dictated by the process. If the slave does satisfy the condition, the process assures that the slave will end up at a state that enables the slave to communicate further with the master.

Three-state machine **304** is part of every slave. A preferred three-state machine is shown in FIG. **4**. Three-state machine **400** includes the three states **401**, **402** and **403**, and all six possible state-to-state transitions **412**, **413**, **421**, **423**, **431** and **432**, where the transitions are between two different states. The three states **401**, **402** and **403** are named S1, S2

and S3, respectively. A transition from a state to itself is not helpful for the methodology described herein.

Other three-state machines are possible. In FIG. **5**, three-state machine **500** has only five of the six state-to-state transitions present in the three-state machine **400**. Three-state machine **500** represents a class of six possible three-state machines where one of the six possible state-to-state transitions is inoperative. In the particular case of FIG. **5**, transition **513** is inoperative.

In FIG. **6**, three-state machine **600** has only four of the six state-to-state transitions of three-state machine **400**. The four operative transitions are such that any state can be reached from another state by means of one or two transitions. Moreover there is at least one possible transition between any two states. Three-state machine **600** represents a class of six possible three-state machines were two of the six possible state-to-state transitions are inoperative, while still providing access to any state from any other state. In the particular case of FIG. **6**, transitions **413** and **432** are inoperative.

In FIG. **7**, three-state machine **700** has only four of the six state-to-state transitions of three-state machine **400**. The four operative transitions are such that any state can be reached from another state by means of one or two transitions. Moreover there are two states between which there is no possible transition. Three-state machine **700** represents a class of three possible three-state machines where one of the pairs of transitions between two states is inoperative. In the particular case of FIG. **7**, the pair of transitions **413** and **431** between states **401** and **403** is inoperative.

In FIG. **8**, three-state machine **800** has only three of the six state-to-state transitions of three-state machine **400**. The three operative transitions are such that any state can be reached from another state by means of one or two transitions. Therefore each pair of states is connected by one and only one transition, in such a way that all transitions move either clockwise or anticlockwise. Three-state machine **800** represents a class of two possible three-state machines that have only three of the six state-to-state transitions. In the particular case of FIG. **8**, the three operative transitions **412**, **423** and **431** define an anticlockwise cycle.

All three-state machines relevant to this invention are listed in FIG. **9**. The six state-to-state transitions **412**, **421**, **423**, **432**, **431** and **413** are named **T12**, **T21**, **T23**, **T32**, **T31** and **T13**, respectively. Each row defines one possible three-state machine. For each state-to-state transition, the existence or not of that transition is indicated. The three-state machine defined by row **900** is a preferred embodiment that corresponds to three-state machine **400** of FIG. **4**. The three-state machines defined by rows **901**, **902**, **903**, **904**, **905**, and **906** belong to the class of three-state machine **500** of FIG. **5**. The three-state machines defined by rows **907**, **908**, **909**, **910**, **911**, and **912** belong to the class of three-state machine **600** of FIG. **6**. The three-state machines defined by rows **913**, **914**, and **915** belong to the class of three-state machine **700** of FIG. **7**. The three-state machines defined by rows **916** and **917** belong to the class of three-state machine **800** of FIG. **8**.

At any one time, each slave is at one and only one of the three states **401**, **402**, or **403**. Accordingly, there are three sets of slaves: those are state **401**, those are state **402**, and those at state **403**. State transitions are equivalent to movement between those three sets. This view of operating over sets is illustrated in FIG. **10**. Set **1001**, named E1, contains as elements all slaves **1010** that are at state **401**. Set **1002**, named E2, contains as elements all slaves **1020** that are at state **402**. Set **1003**, named E3, contains as elements all slaves **1030** that are at state **403**. There are six base commands, irrespective of the condition they specify, for effecting movement of elements between those three sets. Command **1012**, named **T12**, moves elements from set **1001** to set **1002**. Command **1021**, named **T21**, moves elements from set **1002** to set **1001**. Command **1023**, named **T23**, moves elements from set **1002** to set **1003**. Command **1032**, named **T32**, moves elements from set **1003** to set **1002**. Command **1031**, named **T31**, moves elements from set **1003** to set **1001**. Command **1013**, named **T13**, moves elements from set **1001** to set **1003**.

The simplest form of command is illustrated in FIG. **11**. Command **1110** comprises three parameters. First, the "from" state **1101**; second, the "to" state **1102**; and third, the primitive condition **1112** which must be satisfied for the transition to happen. Those three parameters are named Si, Sj, and s, respectively in the figure. Si, the "from" state **1101**, and Sj, the "to" state **1102**, can be any of the three states **401**, **402** or **403**, except that Si and Sj are not equal.

The primitive condition may take many forms depending on the overall capabilities of the slaves and the purposes that underlie the need for selecting subsets of slaves. Such primitive conditions could take the form of equality testing or numerical comparisons. Even though a single command broadcast from the master to the slave can only specify a single primitive condition, arbitrarily complex conditions are realized by a sequence of these primitive commands. In a preferred embodiment, an arbitrarily complex condition is described by a logical equation over primitive conditions. For example, the complex condition A*B+~A*~B, where A and B are primitive conditions, "*" is the binary logical operator AND, "+" the binary logical operator OR, and "~" the unary logical operator NOT. Negated primitive conditions, such as ~A, are assumed to be primitive conditions.

It is convenient for expositional purposes to textually represent command **1110**. A simple syntax used herein is to write the command as Tij(s), where i and j are 1, 2, or 3, corresponding to states **401**, **402** and **403**, respectively, and s is the condition to be satisfied. The prefix T, for transition, is purely cosmetic. For example, **T31**(~A) represents a command to move all slaves that are at the third state and which do not satisfy A, to the first state, while **T23**(1) represents a command to move all slaves that are at the second state to the third state unconditionally.

The six possible transitions **412**, **413**, **421**, **423**, **431** and **432** for some condition s, can thus be written has T12(s), T13(s), T21(s), T23(s), T31(s) and T32(s), respectively. Any command thus involves only two of the three states of a three-state machine and only one of the six possible transitions. The pair of states **1100** in FIG. **11** and the single transition between them defines the scope of a single command. Only slaves that are at state Si, that is the "from" state **1101**, of the pair of states **1100** are allowed to transition, and those that do transition will do it to state Sj, that is the "to" state **1102**. Condition s is tested by each slave that is at state Si. Those for which the condition is satisfied will switch to state Sj. These semantics are expressed by the two logical expressions

$$Ei=Ei*\sim s$$

$$Ej=Ej+Ei*s$$

The first expression states that the set Ei, of all slaves that are at state Si, is decremented by the number of slaves that

move from Si to Sj. That is expressed in the form of a logical AND between the previous value of set Ei and the virtual set of all slaves in Ei that did not satisfy condition s. Concurrently, the second expression states that are the set Ej, of all slaves that are at state Sj, is augmented by the number of slaves that have moved from Si to Sj. That is expressed in the form of a logical OR between the previous value of set Ej and the virtual set of all slaves in Ei that satisfy condition s, the latter expressed by a logical AND between the previous value of set Ei and the virtual set of all slaves in Ei that satisfy condition s.

Since a command **1110** is broadcast to all slaves and they receive and operate on it concurrently, the command is essentially an operation over sets. The command Tij(s) effectively moves elements from a set Ei, of all slaves at state Si, to a set Ej, of all slaves at state Sj. Therefore sets E1, E2 and E3 are associated to states S1, S2 and S3, respectively. Those two notions, sets and states, are for the purpose of this invention functionally equivalent. Reference herein to states S1, S2 and S3 imply sets E1, E2 and E3, and vice versa, respectively.

FIG. **12** illustrates by means of Venn diagrams a simple non limiting example of one of such command. Sets **1001**, **1002** and **1003** correspond to slaves that are in the first, second and third state, respectively. For this example, set **1001** initially contains all slaves, while sets **1002** and **1003** are empty. Three testable primitive conditions A, B and C are defined. Each one of these three primitive conditions defines a virtual subset **1205**, **1206** and **1207**, respectively. The negation of each primitive condition, namely ~A, ~B and ~C, defines three complementary virtual subsets to **1205**, **1206** and **1207**, respectively. Those virtual subsets may or not have slaves in common. In the figure we assume the most difficult case where virtual subsets **1205**, **1206** and **1207** intersect each other. Command T12(A) is broadcast, which forces all slaves in virtual subset **1205** in set **1001** to move from set **1001** to set **1002**. Therefore, after the command is executed by all slaves in this situation, the right half of the figure shows that set **1001** represents the ~A condition, set **1002**, the A condition, and set **1003** is empty.

Note that other Figures in this disclosure that are Venn diagrams have there sets numbered in the same manner as FIG. **12** but that these number are not shown for clarity.

Another example is shown in FIG. **13**. The starting configuration is the same as in FIG. **12**. However, the command T12(~A) is broadcast instead. As the right half of the figure indicates, after the command is executed by all slaves in this situation, set **1001** represents the A condition, set **1002**, the ~A condition, and set **1003** is empty.

A condition that is the product of two or more primitive conditions is obtained by two or more commands. An AND condition A*B, for example, can be obtained by broadcasting two commands. First, T12(A), then T21(~B). Starting from the same initial configuration as used in FIG. **12**, execution of T12(A) is shown in FIG. **12**. Execution of command T21(~B) on that resulting configuration is shown in FIG. **14**. As the right half of the figure indicates, after the two commands are executed in succession by all slaves in this situation, set **1001** represents the ~(A*B) condition, set **1002**, the A*B condition, and set **1003** is empty. Therefore, set **1002** represents an AND condition, while set **1001** represents the complementary NAND condition.

A condition that is the sum of two or more primitive conditions is obtained by two or more commands. An OR condition A+B, for example, can be obtained by broadcasting two commands. First, T12(A), then T12(B). Starting from the same initial configuration as used in FIG. **12**, execution of T12(A) is shown in FIG. **12**. Execution of command T12(B) on that resulting configuration is shown in FIG. **15**. As the figure indicates, after the two commands are executed in succession by all slaves in this situation, set **1001** represents the ~(A+B) condition, set **1002**, the A+B condition, and set **1003** is empty. Therefore, set **1002** represents an OR condition, while set **1001** represents the complementary NOR condition.

The previous two examples involve only two of the possible three sets. Some conditions require the use of all three sets. The only two conditions involving two primitive conditions A and B that require all three sets are the EXCLUSIVE-OR, A*~B+~A*B, and its complement the EQUIVALENCE, A*B+~A*~B. (See discussion of left nested expressions below.) The EXCLUSIVE-OR can be obtained by broadcasting a sequence of three commands: T12(~A), T13(B) and T21(B). Execution of the three commands is shown in FIGS. **13**, **16**, and **17**. This sequence is more compactly represented in tabular form as done in FIG. **18**. Row **1800** of the table is the initial state of the three sets. In this example, set **1001** has all slaves and sets **1002** and **1003** are empty. Rows **1801**, **1802** and **1803** show the result of executing commands T12(~A), T13(B) and T21(B), respectively, and the resulting conditions expressed by each of the three sets after each command is executed. As FIG. **18** shows, after the three commands are executed in succession by all slaves in this situation, set **1001** represents the A*~B+~A*B condition, set **1002**, the ~A*~B condition, and set **1003**, the A*B condition. As is, the slaves that satisfy the EXCLUSIVE-OR condition ended up in set **1001**. If the goal had been to place those slaves in set **1002** instead, a different sequence of commands would be broadcast. That sequence is shown in FIG. **19**. Rows **1900**, **1901**, **1902** and **1903** of the table show the initial and succeeding conditions obtained in each set during the execution of the sequence of commands T12(A), T23(B) and T12(B). if the goal had been to place the EXCLUSIVE-OR in set **1003** instead, a different sequence of commands would be broadcast. That sequence is shown in FIG. **20**. Rows **2000**, **2001**, **2002** and **2003** of the table show the initial and succeeding conditions obtained in each set during the execution of the sequence of commands T13(A), T32(B) and T13(B).

The present invention teaches several methods for generating a command sequence necessary to select slaves that satisfy an arbitrarily complex condition involving any number of primitive conditions. Before describing the most general methods, the invention first teaches a few important methods aimed at certain types of complex conditions. Non limiting examples of command sequences are given in the columns numbered **1810** (in FIG. **18**), **1910** (in FIG. **19**), **2010** (in FIG. **20**), **2610** (in FIG. **26**), **2710** (in FIG. **27**), **2910** (in FIG. **29**), **3010** (in FIG. **30**), **3210** (in FIG. **32**), **3310** (in FIG. **33**), **3510** (in FIG. **35**), **3610** (in FIG. **36**), **3910** (in FIG. **39**), and **4010** (in FIG. **40**).

Each command, T, sent from the master to one or more slaves, has a single primitive condition, ci, that is one of any number of arbitrary primitive conditions. The command, T, addresses some information stored on each of the slaves and causes the respective slave to compare its stored information with the primitive condition.

The first of those is a condition expressed by the product of two or more primitive conditions. This is the general AND condition and the method for handling that kind of condition is shown in FIG. **21**. Method **2100** takes an input **2101** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and an AND of N primitive conditions, that is, c1*c2* . . . *cN. Method **2100** outputs a configuration **2102** whereby

all slaves in set Ej that satisfied the aforementioned AND condition have moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in Ek that did not satisfy the reduced condition c2* . . . *cN have moved to set Ej. That can be represented mathematically as

Ej=Ej*~(c1*c2* . . . *cN)+Ek*~(c2*c3* . . . *cN)

Ek=Ej*(c1*c2* . . .*cN)+Ek*(c2*c3* . . . *cN)

Method **2100** accomplishes this by generating a sequence of N commands. In step **2110**, a command is issued that causes all slaves in set Ej that satisfy first primitive condition c1 to move to set Ek. This command is written as Tjk(c1). The state transitions effected can be mathematically represented as

Ej=Ej*~c1

Ek=Ek+Ej*c1

Step **2120** controls the iteration over all remaining primitive conditions that make up the input AND condition **2101**. For each primitive condition ci, where i varies from 2 to N, step **2121** issues a command that causes all slaves in set Ek that do not satisfy primitive condition ci to move to set Ej. This command is written as Tkj(~ci). The state transitions effected can be mathematically represented as

Ej=Ej+Ek*~c1

Ek=Ek*c1

The iteration ends after the last primitive condition, cN, has been processed by step **2121**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2100** are exactly those that satisfy the AND condition.

The second is a condition expressed by the negation of a product of two or more primitive conditions. This is the general NAND condition and the method for handling that kind of condition is shown in FIG. **22**. Method **2200** takes as input **2201** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and a NAND of N primitive conditions, that is, ~(c1*c2* . . . *cN). Method **2200** outputs a configuration **2202** whereby all slaves in set Ej that satisfy the aforementioned NAND condition are moved to set Ek. That can be represented mathematically as

Ej=Ej*(c1*c2* . . . *cN)

Ek=Ek+Ej*~(c1*c2* . . . *cN)

The method **2200** accomplishes this by generating a sequence of N commands. The main step **2220** controls the iteration over all the primitive conditions that make up the input NAND condition. For each primitive condition ci, where i varies from 1 to N, step **2221** issues a command that causes all slaves in set Ej that do not satisfy primitive condition ci to move to set Ek. This command is written as Tjk(~ci). The state transitions effected can be mathematically represented as

Ej=Ej*c1

Ek=Ek+Ej*~c1

The iteration ends after the last primitive condition, cN, has been processed by step **2221**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2200** are exactly those that satisfy the NAND condition.

The third is a condition expressed by the sum of two or more primitive conditions. This is the general OR condition and the method for handling that kind of condition is shown in FIG. **23**. Method **2300** takes as input **2301** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and an OR of N primitive conditions, that is, c1+c2+ . . . +cN. Method **2300** outputs a configuration **2302** whereby all slaves in set Ej that satisfy the aforementioned OR condition are moved to set Ek. That can be represented mathematically as

Ej=Ej*~(c1+c2+ . . . +cN)

Ek=Ek+Ej*(c1+c2+ . . . +cN)

Method **2300** accomplishes this by generating a sequence of N commands. The main step **2320** controls the iteration over all the primitive conditions that make up the input OR condition. For each primitive condition ci, wherein i varies from 1 to N, step **2321** issues a command that causes all slaves in set Ej that satisfy primitive condition ci to move to set Ek. This command is written as Tjk(ci). The state transitions effected can be mathematically represented as

Ej=Ej*~c1

Ek=Ek+Ej*c1

The iteration ends after the last primitive condition, cN, has been processed by step **2321**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2300** are exactly those that satisfy the OR condition.

The fourth is a condition expressed by the negation of the sum of two or more primitive conditions. This is the general NOR condition and the method for handling that kind of condition is shown in FIG. **24**. Method **2400** takes as input **2401** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and a NOR of N primitive conditions, that is, ~(c1+c2+ . . . +cN). Method **2400** outputs a configuration **2402** whereby all slaves in set Ej that satisfy the aforementioned NOR condition are moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in Ek that satisfied the reduction condition c2+ . . . +cN have moved to set Ej. That can be represented mathematically as

Ej=Ej*(c1+c2+ . . . +cN)+Ek*(c2+c3+ . . . +cN)

Ek=Ej*~(c1+c2+ . . . +cN)+Ek*~(c2+c3+ . . . +cN)

Method **2400** accomplishes this by generating a sequence of N commands. In step **2410**, a command is issued that causes all slaves in set Ej that do not satisfy first primitive condition c1 to move to set Ek. This command is written as Tjk(~c1). The state transitions effected can be mathematically represented as

Ej=Ej*c1

Ek=Ek+Ej*~c1

Step **2420** then controls the iteration over all the remaining primitive conditions that make up the input NOR condition. For each primitive condition ci, where i varies from 2 to N, step **2421** issues a command that causes all slaves in set Ek that satisfy primitive condition ci to move to set Ej. This command is written as Tkj(ci).

Ej=Ej+Ek*ci

Ek=Ek*~ci

The iterative step **2420** ends after the last primitive condition, cN, has been processed by step **2421**. That terminates the method.

In a preferred embodiment, Ek begins as a null set so that the slaves that are found in Ek at the end of method **2400** are exactly those that satisfy the NOR condition.

Methods **2100, 2200, 2300** and **2400** can be combined to handle arbitrarily complex conditions. The simplest such combination is called canonical, because it is based on the well-known technique of expressing an arbitrarily complex condition in the form of sum-of-products, i.e. one or more ANDed primitive conditions that are ORed together. The canonical method works by computing each product term of the condition using two sets and accumulating, that is summing, the product terms into a third set.

FIG. **25** shows a method **2500** that moves slaves from the first to the second state and visa versa. When slaves are in the second state, it is possible to move them to the third state where all remaining commands in the command sequence are ignored. Method **2500** takes as input **2501** three different sets Ej, Ek, and El, that is, some permutation of sets E1, E2 and E3, and a condition that is a sum of P product terms, that is, p1+p2+ . . . +pP. Assuming, for simplicity, that set Ek is empty at the start of the method. Method **2500** outputs a configuration **2502** whereby all slaves in set Ej that satisfy the aforementioned sum-of-products condition are moved to set El. That can be represented mathematically as

Ej=Ej*~(p1+p2+ . . . +pP)

Ek=0

El=El+Ej*(p1+p2+ . . . +pP)

Method **2500** accomplishes this by generating a sequence of commands. The main step **2520** controls the iteration over all the product terms that make up the input sum-of-products condition **2501**. For each product term pi, where i varies from 1 to P, first step **2521** issues a sequence of commands as defined by method **2100** that causes all slaves in set Ej that satisfy the product term pi to move to set Ek. Second step **2522** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last product term, pP, has been processed by steps **2521** and **2522**. That terminates the method.

In other words, the method **2500** creates each of the product terms in **2521** and in set Ek. After each product term, pi, is created, it is ORed with the previously accumulated product terms in set El. That frees up set Ek in preparation for the next product term.

Applying the method **2500** to the EXCLUSIVE-OR condition ~A*B+A*~B, for example, results in the command sequence **2610** shown in FIG. **26**. The default initial configuration **2600** where all the slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Commands T12(~A) and T21(~B), as per method **2100**, are used to move slaves that satisfy the product term ~A*B from set E1 to set E2, as shown by rows **2601** and **2602**. Command T23(l) sums that product term from E2 to E3, as shown in row **2603**. That is the basic cycle for one product term. Next, commands T12(A), T21(B) and T23(l) repeat the cycle to move slaves that satisfy the next product term A*~B first from set E1 to set E2 and second from set E2 to set E3, as shown by rows **2604, 2605** and **2606**. Six commands are generated by method **2500** for the EXCLUSIVE-OR condition, two of those on account of two product terms and the other four on account of four primitive conditions present over all product terms. Contrast this with the three commands generated by any the hand crafted solution of FIGS. **18, 19** and **20**. While the canonical method is easy to compute, the command sequences it generates are not minimal in general.

An arbitrarily complex condition can be written in the form of a sum-of-products. A canonical method for generating a command sequence for a sum-of-products is to use first and second states to calculate product terms and to use the third state to accumulate the product terms. The canonical method does not yield the shortest command sequence but is easy to compute.

When a complex condition is put in sum-of-product form, the products do not have to be expanded so that each contains all primitive conditions used in the complex condition. For an example which includes three primitive conditions A, B, and C, the complex condition A*~B*C+A*B*C+~A*B*C+A*B*C can be minimized to A*C+B*C and still be considered a sum-of-products for the purpose of method **2500** and other methods described hereunder. Such a minimization represents a significant reduction in commands required. While the fully expanded condition above would require sixteen commands (four product terms and twelve primitive condition appearances), the corresponding minimized sum-of-products requires six commands (two product terms and four primitive condition appearances), when both the command sequences are generated through the canonical method **2500**. The six commands solution **2710** is shown in FIG. **27** and not surprisingly mimics the command sequence **2610** of FIG. **26**. Again a default initial configuration **2700** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Command T12(A) transfers from set E1 to set E2 the slaves in set E1 that satisfy primitive condition A. Row **2701** indicates that set E1 contains the slaves that satisfy condition ~A; set E2, condition A; and set E3 is empty. Command T21(~C) transfers from set E2 to set E1 the slaves in set E2 that do not satisfy primitive condition C. Row **2702** indicates that set E1 represents condition ~A+A*~C, which is equivalent to ~A+~C; set E2, condition A*C; and set E3 is empty. Command T23(l) transfers from set E2 to set E3 all slaves in set E2. Row **2703** indicates the accumulation of product term A*C into set E3. Command T12(B) transfers from set E1 to set E2 the slaves in set E1 that satisfy primitive condition B. Row **2704** indicates that set E1 represents the condition (~A+~C)*~B, which is equivalent to condition ~A*~B+~B*~C; and set E2, condition (~A+~C)*B, which is equivalent to ~A*B+B*~C. Command T21(~C) transfers from set E2 to set E1 the slaves in set E2 that do not satisfy primitive condition C. Row **2705** indicates that set E1 represents condition ~A*~B+~B*~C+(~A*B+B*~C)*~C, which reduces to ~A*~B+~B*~C+~A*B*~C+B*~C, then to ~A*~B+~B*~C+B*~C, then to ~A*~B+~C; and set E2 represents condition (~A*B+B*~C)*C, which is equivalent to ~A*B*C. Command T23(l) transfers from set E2 to set E3 all slaves in set E2. Row **2706** indicates that set E3 represents the condition A*C+~A*B*C, which reduces to (A+~A*B)*C, then to (A+B)*C, then to A*C+B*C, which is the sum-of-product condition that needed to be satisfied. Applying method **2500** to a minimized sum-of-products, as in this example, will generate a command sequence that is certainly shorter than a fully-expanded sum-of-products, but is still not necessarily minimal.

Characteristic of method **2500** is that the first set Ej serves as the main repository of slaves and will end up containing the slaves originally in set Ej that do not satisfy the sum-of-products condition. Second set Ek serves to build each product term. Third set El serves to sum the product terms and will end up containing the slaves originally in set Ej that

satisfy the sum-of-products condition. Therefore, for method **2500**, each of the three sets has a uniquely defined role.

This does not need to be the case and one can create variations of method **2500** where the roles alternate. The method shown in FIG. **28** is one such variation. Method **2800** differs from method **2500** in that the roles of states Ej (state 1) and Ek (state 2) alternate, i.e. states 1 and 2 reverse roles. Product terms are build alternatively in states Ek and Ej: first, in Ek, then in Ej, then back in Ek, and so on; in other words, odd product terms—first, third, fifth, etc.—are built in set Ek, while even product terms—second, fourth, sixth, etc.—are built in set Ej. Method **2800** is similar to method **2500** in that the role of state El remains the same. Method **2800** takes as input **2801** the same input as does method **2500**. Method **2800** outputs a configuration whereby all slaves in Ej that satisfy the sum-of-products condition are moved to set El, and either set Ej or Ek will be empty depending on the number of product terms. If the condition has an even number of product terms, Ek will be empty; otherwise, Ej will be empty. That can be represented mathematically as

El=El+Ej*(p1+p2+ . . . +pP)

(if P is even) Ej=Ej*~(p1+p2+ . . . +pP)

(if P is odd) Ej=0

(if P is even) Ek=0

(if P is odd) Ek=Ej*~(p1+p2+ . . . +pP)

The main step **2820** controls the iteration over all the product terms that make up the sum-of products condition **2801**. For each product term pi, where i varies from 1 to P, step **2830** tests whether i is odd or even. If i is odd, steps **2831** and **2833** are executed for product term pi. If i is even, steps **2832** and **2834** are executed for product term pi. Step **2831** issues a sequences of commands defined by NAND method **2200** that causes all slaves in set Ej that do not satisfy product term pi to move to set Ek. Step **2833** issues a command that causes all slaves in set Ej to move to set El. Similarly, step **2832** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set Ek that do not satisfy product term pi to move to set Ej. Step **2834** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last product term, pP, has been processed by either steps **2831** and **2833** (odd P case), or steps **2832** and **2834** (even P case). That terminates the method.

If method **2800** is used on the EXCLUSIVE-OR condition ~A*B+A*~B, the sequence of commands **2910** shown in FIG. **29** results. The default initial configuration **2900** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **2901** and **2902** correspond to the application of method **2200** from E1 to E2 to the product term ~A*B. Row **2903** is the accumulation of that product term in E3. Rows **2904** and **2905** correspond to the application of method **2200** from E2 to E1 to the product term A*~B. Row **2906** is the accumulation of that product term in E3. Because the number of product term is even in this case, E2 is empty at the end.

A similar sequence of commands results if method **2800** is used on the condition A*C+B*C. The sequence of commands **3010** is shown in FIG. **30**. The default initial configuration **3000** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3001** and **3002** correspond to the application of method **2200** from E1 to E2 to the product term A*C. Row **3003** is the accumulation of that product term in E3. Rows **3004** and **3005** correspond to the application of method **2200** from E2 to E1 to the product term B*C. Row **3006** is the accumulation of that product term in E3. Because the number of product term is even in this case, E2 is empty at the end.

The method shown in FIG. **31** differs from methods **2500** and **2800** in that both the building of product terms and the accumulation of product terms alternates between two sets. Specifically, the roles of set Ek (state 2) and El (state 3) reverse. With method **3100** product terms are either computed from set Ej to set Ek or from set Ej to set El. While for methods **2500** and **2800** summing was done by adding the latest product term into the previous accumulation, with method **3100** the previous accumulation is added to the latest product term. Accordingly, when the latest product term is built in set Ek, accumulation is from El to Ek, and when the latest product term is built in set El, accumulation is from Ek to El. Method **3100** takes as input **3101** the same input as do methods **2500** and **2800**. Method **3100** outputs a configuration whereby all slaves in Ej that satisfy the sum-of-products condition are moved to either set Ek or El depending on the number of product terms. If the condition has an even number of product terms, El will contain the desired slaves; otherwise, Ek will. That can be represented mathematically as

Ej=Ej*~(p1+p2+ . . . +pP)

(if P is odd) Ek=El+Ej*(p1+p2+ . . . +pP)

(if P is even) Ek=0

(if P is odd) El=0

(if P is even) El=El+Ej*(p1+p2+ . . . +pP)

The main step **3120** controls the iteration over all the product terms that make up the sum-of-products condition **3101**. For each product term pi, where i varies from 1 to P, step **3130** tests whether i is odd or even. If i is odd, steps **3131** and **3133** are executed for product term pi. If i is even, steps **3132** and **3134** are executed for product term pi. Step **3131** issues a sequence of commands defined by AND method **2100** that causes all slaves in set Ej that satisfy product term pi to move to set Ek. Step **3133** issues a command that causes all slaves in set El to move to set Ek. Similarly, step **3132** issues a sequence of commands defined by AND method **2100** that causes all slaves in set Ej that satisfy product term pi to move to set El. Step **3134** issues a command that causes all slaves in set Ek to move to set El. The iterative step **3120** ends after the last product term, pP, has been processed by either steps **3131** and **3133** (odd P case), or steps **3132** and **3134** (even P case). That terminates the method.

If method **3100** is used on the EXCLUSIVE-OR condition ~A*B+A*~B, the sequence of commands **3210** shown in FIG. **32** results. The default initial configuration **3200** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3201** and **3202** correspond to the application of method **2100** from E1 to E2 to the product term ~A*B. Row **3203** is the accumulation of E3 into that product term. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3204** and **3205** correspond to the application of method **2100** from E1 to E3 to the product term A*~B. Row **3206** is the accumulation of E2 into that product term. Because the number of product terms is even in this case, E3 contains the desired set of slaves.

A similar sequence of commands results if method **3100** is used on the condition A*C+B*C. The sequence of commands **3310** is shown in FIG. **33**. The default initial configuration **3300** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3301** and **3302** correspond to the application of method **2100** from E1 to E2 to the product term A*C. Row **3303** is the accumulation of E3 into that product term. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3304** and **3305** correspond to the application of method **2100** from E1 to E3 to the product term B*C. Row **3306** is the accumulation of E2 into that product term. Because the number of product term is even in this case, E3 contains the desired set of slaves.

The method shown in FIG. **34** differs from methods **2500**, **2800** and **3100** in that the building of product terms and the accumulation of those product terms rotates among three sets, i.e., the states cycle roles. Methods **3400** takes as input **3401** the same input as do methods **2500**, **2800** and **3100**. Method **3400** outputs a configuration whereby all slaves in set Ej that satisfy the sum-of-products condition are moved to set Ej, Ek or El depending on the number of product terms. If the number of product terms modulo **3** is one, that is, 1, 4, 7, etc., set Ej will end up containing the desired set of slaves. If the number of product terms modulo **3** is two, that is, 2, 5, 8, etc., set Ek will end up containing the desired set of slaves. If the number of product terms modulo **3** is zero, that is, 3, 6, 9, etc., set El will end up containing the desired set of slaves. That can be represented mathematically as

(if (P mod 3)=1) Ej=El+p1+p2+ . . . +pP, El=0

(if (P mod 3)=2) Ek=El+p1+p2+ . . . +pP, Ej=0

(if (P mod 3)=0) El=El+p1+p2+ . . . +pP, Ek=0

The main step **3410** controls the iteration over all product terms that make up the sum-of-products condition **3401**. For each product term pi, where i varies from 1 to P, step **3420** tests whether i mod **3** is one, two or zero. If one, steps **3421** and **3424** are executed for product term pi. If two, steps **3422** and **3425** are executed for product term pi. If zero, steps **3423** and **3426** are executed for product term pi. Step **3421** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set Ej that do not satisfy product term pi to move to set Ek. Step **3424** issues a command that causes all slaves in set El to move to set Ej. Similarly, step **3422** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set Ek that do not satisfy product term pi to move to set El. Step **3425** issues a command that causes all slaves in set Ej to move to set Ek. Similarly, step **3423** issues a sequence of commands defined by NAND method **2200** that causes all slaves in set El that do not satisfy product term pi to move to set Ej. Step **3426** issues a command that causes all slaves in set Ek to move to set El. The iterative step **3410** ends after the last product term, pP, has been processed. That terminates the method.

If method **3400** is used on the EXCLUSIVE-OR condition ~A*B+A*~B, the sequence of commands **3510** shown in FIG. **35** results. The default initial configuration **3500** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3501** and **3502** correspond to the application of method **2200** from E1 to E2 to the negated product term ~(~A*B). Row **3503** is the accumulation of E3 into E1. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3504** and **3505** correspond to the application of method **2200** from E2 to E3 to the negated product term ~(A*~B). Row **3506** is the accumulation of E1 into E2. Because the number of product terms modulo three is two in this case, E2 contains the desired set of slaves.

A similar sequence of commands results if method **3500** is used on the condition A*C+B*C. The sequence of commands **3610** is shown in FIG. **36**. The default initial configuration **3600** where all slaves are in set E1 is used. In this example, j=1, k=2 and l=3. Rows **3601** and **3602** correspond to the application of method **2200** from E1 to E2 to the negated product term ~(A*C). Row **3603** is the accumulation of E3 into E1. Because E3 is empty, this command is unnecessary but is included as part of the normal cycle. Rows **3604** and **3605** correspond to the application of method **2200** from E2 to E3 to the negated product term ~(B*C). Row **3606** is the accumulation of E1 into E2. Because the number of product terms modulo three is two in this case, E2 contains the desired set of slaves.

Methods **2500**, **2800**, **3100** and **3400** do not in general generate a minimal sequence of commands for a given arbitrarily complex condition expressed in sum-of-products form. A shorter command sequence can be obtained when an arbitrarily complex condition can be written by an expression that can be generated by the following grammar:

In-expression: (In-expression)*primitive_condition

In-expression: In-expression+primitive_condition

In-expression: primitive_condition

where In-expression is the name given to this kind of expression, namely, left-nesting expression. A In-expression can be written as, ((. . . (((c1) op2 c2) op3 c3) . . .)opN cN), wherein c1, c2, . . . , cN are primitive conditions and op2, op3, . . . , opN are either *(AND) or +(OR) binary operators. The In-expression as written above is more heavily parenthetically bracketed than necessary and some parenthesis may be deleted as long as the logic is preserved. Left-nesting expressions can be executed using only two of the three states of the three-state machine. An arbitrarily complex condition such as A*B+A*C can be expressed according to the grammar as (B+C)*A. The aforementioned canonical method over the former, sum-of-products, expression requires six commands to execute and uses three states. The latter, left-nesting, expression can be computed with only three commands and uses only two states. Not every arbitrarily complex conditions can be expressed by a single left-nested expression, but any complex condition can be expressed by a sum of left-nested expressions, which requires fewer commands than the canonical sum-of-products form. For example, the condition A*B+A*C+~A*~B+~A*~C can be written as a sum of two left-nested expressions: (B+C)*A+(~B+~C)*~A; the former requires twelve commands, while the latter only eight. As with the canonical sum-of-products method, which uses the third state to accumulate products, the method for executing sum-of-left-nested-expressions uses the third state to accumulate left-nested expressions.

As mentioned above, the present three-selection-state machine is capable of isolating or selecting slaves that satisfy any possible condition expressed by a left-nested expression. Specifically, the invention is necessary and sufficient to isolate and select slaves satisfying those conditions that are expressed by a sum-of-left-nested-expressions. The invention enables this capability because a separate condition (or set of conditions), each corresponding

to a set of slaves, can be isolated in any one of the three states at any given time. Therefore, operations on two sets of conditions, in two of the respective states, can be performed without affecting or being affected by the conditions held in the third state. Specific instances of left-nested-expressions handled by the invention are now presented.

The method for computing the sequence of commands necessary to transfer from a set Ej to a set Ek slaves in set Ej that satisfy a condition given as a In-expression is shown in FIG. **37**. Method **3700** takes as input **3701** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and a In-expression, ((. . . (((c1) op2 c2) op3 c3) . . .) opN cN). Method **3700** outputs a configuration **3702** whereby all slaves in set Ej that satisfy the In-expression of input **3701** are moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in set Ek that did not satisfy the reduced condition (. . . ((cM) op . . .) . . . opN cN), where M is such that opM is the first * (AND) operator in the In-expression, have moved to set Ej. That can be represented mathematically as

Ej=Ek*~((cm op . . .) opN cN)+Ej*~((c1 op . . .) opN cN)

Ek=Ek* ((cm op . . .) opN cN)+Ej* ((c1 op . . .) opN cN)

where m such that op2, op3, . . . , opm-1=OR and opm'AND

Method **3700** begins with step **3710**, which issues a command that causes all slaves in set Ej that satisfy the leftmost (first) primitive condition c1 to move to set Ek. Step **3720** controls the iteration over the binary operators and attendant right operands, from the leftmost to the rightmost, that is, from op2 to opN and their attendant c2 to cN. For each operator opi, where i varies from 2 to N, step **3730** tests which binary operator is opi. If opi is the AND operator *, step **3731** is executed; otherwise, opi is the OR operator +, in which case step **3732** is executed. Step **3731** issues a command that causes all slaves in set Ek that do not satisfy primitive condition ci to move to set Ej. Step **3732** issues a command that causes all slaves in set Ej that satisfy primitive condition ci to move to set Ek. After the last iteration, over opN and cN, step **3720** terminates the iteration. That terminates the method.

An important variation of method **3700** is shown in FIG. **38**. Method **3800** computes the sequence of commands necessary to transfer from a set Ej to a set Ek slaves in set Ej that satisfy a condition given as the negation of a In-expression. Method **3800** takes as input **3801** two different sets Ej and Ek of the possible three sets E1, E2 and E3, and a condition in the form of a negated In-expression, ~((. . . (((c1) op2 c2) op3 c3) . . .) opN cN). Method **3800** outputs a configuration **3802** whereby all slaves in set Ej that satisfy the negated In-expression of input **3801** are moved to set Ek. If set Ek was not empty to start with, a side effect of the method is that all slaves originally in set Ek that did not satisfy the reduced condition ~(. . . ((cM) op . . .) . . . opN cN), where M is such that opM is the first + (OR) operator in the In-expression, have moved to set Ej. That can be represented mathematically as

Ej=Ek* ((cm op . . .) opN cN)+Ej* ((c1 op . . .) opN cN)

Ek=Ek*~((cm op . . .) opN cN)+Ej*~((c1 op . . .) opN cN)

where m such that op2, op3, . . . , opm-1=AND and opm=OR

Method **3800** begins with step **3810**, which issues a command that causes all slaves in set Ej that do not satisfy the leftmost (first) primitive condition c1 to move to set Ek. Step **3820** controls the iteration over the binary operators and attendant right operands, from the leftmost to the rightmost, that is, from op2 to opN and their attendant c2 to cN. For each operator opi, where i varies from 2 to N, step **3830** tests which binary operator is opi. If opi is the OR operator +, step **3831** is executed; otherwise, opi is the AND operator *, in which case step **3832** is executed. Step **3831** issues a command that causes all slaves in set Ek that satisfy primitive condition ci to move to set Ej. Step **3832** issues a command that causes all slaves in set Ej that do not satisfy primitive condition ci to move to set Ek. After the last iteration, over opN and cN, step **3820** terminates. That terminates the method.

By expressing the minimized sum-of-products condition A*C+B*C, used in previous examples, as an In-expression (A+B)*C, either method **3700** or **3800** can be used to generate a sequence of commands that is shorter than the sequence generated by method **2500**, **2800**, **3100** or **3400**. The latter sequence is six commands long, as shown in FIGS. **27**, **30**, **33**, and **36**. Both methods **3700** and **3800** generate a sequence that is three commands long. The example sequence **3910** generated by method **3700** is shown in FIG. **39**. The example sequence **4010** generated by method **3800** is shown in FIG. **40**. They both start with the default initial configuration where all slaves are in set E1, as shown in rows **3900** and **4000**. In both examples j=1, k=2 and l=3. Method **3700** generates the sequence T12(A), T12(B) and T21(~C). Commands T12(A) and T12(B) put the partial condition (A+B) in set E2 as shown in rows **3901** and **3902**. Command T21(~C) results in the desired condition (A+B)*C in set E2 as shown in row **3903**. Method **3800** generates the sequence T12(~A), T21(B) and T12(~C). Commands T12(~A) and T21(B) put the partial condition (A+B) in set E1 as shown in rows **4001** and **4002**. Command T12(~C) results in the desired condition (A+B)*C in set E1 as shown in row **4003**.

Note from the method descriptions of FIGS. **37** and **38**, and the examples of FIGS. **39** and **40**, that the third set E3 is not used. It is an important property of conditions written as a single In-expression, that they require only two of the three states of a three-state machine. This property permits the use of the third state, that is, of set E3, as an accumulator of In-expressions. While not all arbitrarily complex conditions can be expressed by a single In-expression, any arbitrary complex condition can be expressed by a sum-of-In-expressions. It is possible therefore to recode methods **2500**, **2800**, **3100** and **3400** to work on sum-of-In-expressions.

Method **2500** is recoded in FIG. **41** for sum-of-In-expressions. Method **4100** takes as input **4101** three sets Ej, Ek and El, that is, some permutation of sets E1, E2 and E3, and a condition written as a sum-of-In-expressions, n1+n2+ . . . +nN. Assuming, for simplicity, that set Ek is empty at the start of the method. Method **4100** outputs a configuration **4102** whereby all slaves in set Ej that satisfy the sum-of-In-expressions condition **4101** are moved to set El. That can be represented mathematically as

Ej=Ej*~(n1+n2+ . . . +nN)

Ek=0

El=El+Ej*(n1+n2+ . . . +nN)

The main step **4120** controls the iteration over all In-expressions of condition **4101**. For each In-expression ni, where i varies from 1 to N, steps **4121** and **4122** are executed in that order. Step **4121** issues a sequence of commands defined by method **3700** that causes all slaves in set Ej that satisfy the In-expression ni to move to set Ek. Step **4122** issues a command that causes all slaves in set Ek to move to

set El. Iteration ends after the last In-expression, nN, has been processed. That terminates the method.

Method **2800** is recoded in FIG. **42** for sum-of-In-expressions. Method **4200** takes as input **4201** the same input as does method **4100**. Method **4200** outputs a configuration **4202** whereby all slaves in Ej that satisfy the sum-of-In-expressions condition **4201** are moved to set El, and either set Ej or set Ek will be empty depending on the number of In-expressions. If the condition has an even number of In-expressions, set Ek will be empty; otherwise, set Ej will be empty. That can be represented mathematically as

El=El+Ej*(n1+n2+ . . . +nN)

(if N is even) Ej=Ej*~(n1+n2+ . . . +nN), Ek=0

(if N is odd) Ek=Ej*~(n1+n2+ . . . +nN), Ej=0

The main step **4220** controls the iteration over all In-expressions of condition **4201**. For each In-expression ni, where i varies from 1 to N, step **4230** tests whether i is odd or even. If i is odd, steps **4231** and **4233** are executed for In-expression ni. If i is even, steps **4232** and **4234** are executed for In-expression ni. Step **4231** issues a sequence of commands defined by method **3800** that causes all slaves in set Ej that do not satisfy In-expression ni to move to set Ek. Step **4233** issues a command that causes all slaves in set Ej to move to set El. Similarly, step **4232** issues a sequence of commands defined by method **3800** that causes all slaves in set Ek that do not satisfy In-expression ni to move to set Ej. Step **4234** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last In-expression, nP, has been processed by either steps **4231** and **4233**, or steps **4232** and **4234**. That terminates the method.

Method **3100** is recoded in FIG. **43** for sum-of-In-expressions. Method **4300** takes as input **4301** the same input as do methods **4100** and **4200**. Method **4300** outputs a configuration **4302** whereby all slaves in set Ej that satisfy the sum-of-In-expressions condition **4301** are moved to either set Ek or set El depending on the number of In-expressions. If the condition has an even number of In-expressions, set El will contain the desired slaves; otherwise, set Ek will. That can be represented mathematically as

Ej=Ej*~(n1+n2+ . . . +nN)

(if N is odd) Ek=El+Ej*(n1+n2+ . . . +nN), El=0

(if N is even) El=El+Ej*(n1+n2+ . . . +nN), Ek=0

The main step **4320** controls the iteration over all In-expressions of condition **4301**. For each In-expression ni, where i varies from 1 to N, step **4330** tests whether i is odd or even. If i is odd, steps **4331** and **4333** are executed for In-expression ni. If i is even, steps **4332** and **4334** are executed for In-expression ni. Step **4331** issues a sequence of commands defined by method **3700** that causes all slaves in set Ej that satisfy In-expression ni to move to set Ek. Step **4333** issues a command that causes all slaves in set El to move to set Ek. Similarly, step **4332** issues a sequence of commands defined by method **3700** that causes all slaves in set Ej that satisfy In-expression ni to move to set El. Step **4334** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last In-expression, nN, is processed. That terminates the method.

Method **3400** is recoded in FIG. **44** for sum-of-In-expressions. Method **4400** takes as input **4401** the same input as do methods **4100**, **4200** and **4300**. Method **4400** outputs a configuration **4402** whereby all slaves in set Ej that satisfy the sum-of-In-expressions condition **4401** are moved to set Ej, Ek or El depending on the number of In-expressions. If the number of In-expressions modulo three is one, that is, 1, 4, 7, etc., set Ej will end up containing the desired set of slaves. If the number of In-expressions modulo three is two, that is, 2, 5, 8, etc., set Ek will end up containing the desired set of slaves. If the number of In-expressions modulo three is zero, that is, 3, 6, 9, etc., set El will end up containing the desired set of slaves. That can be represented mathematically as

(if (N mod 3)=1) Ej=El+Ej*(n1+n2+ . . . +nN), El=0

(if (N mod 3)=2) Ek=El+Ej*(n1+n2+ . . . +nN), Ej=0

(if (N mod 3)=0) El=El+Ej*(n1+n2+ . . . +nN), Ek=0

The main step **4410** controls the iteration over all In-expressions of condition **4401**. For each In-expression ni, where i varies from 1 to N, steps **4419** and **4420** test whether i mod **3** is one, two or zero. If one, steps **4421** and **4424** are executed for In-expression ni. If two, steps **4422** and **4425** are executed for In-expression ni. If zero, steps **4423** and **4426** are executed for In-expression ni. Step **4421** issues a sequence of commands defined by method **3800** that causes all slaves in set Ej that do not satisfy In-expression ni to move to set Ek. Step **4424** issues a command that causes all slaves in set **E1** to move to set Ej. Similarly, step **4422** issues a sequence of commands defined by method **3800** that causes all slaves in set Ek that do not satisfy In-expression ni to move to set El. Step **4425** issues a command that causes all slaves in set Ej to move to set Ek. Similarly, step **4423** issues a sequence of commands defined by method **3800** that causes all slaves in set El that do not satisfy In-expression ni to move to set Ej. Step **4426** issues a command that causes all slaves in set Ek to move to set El. The iteration ends after the last In-expression, nN, is processed. That terminates the method.

For example, the condition A*B+A*C+~A*~B*~C, which would require ten commands if handled by any of methods **2500**, **2800**, **3100** or **3400**, can be rewritten as (B+C)*A+~A*~B*~C and handled by any of methods **4100**, **4200**, **4300** or **4400**, in which case only eight commands are necessary. In the particular case of method **4100** the eight commands are T12(B), T12(C), T21(~A), T23(1), T12(~A), T21(B), T21(C), and T23(1).

As evident by the examples and method descriptions, not all possible transitions of the three-state machine need be available. Methods **2500** and **4100** can be executed on any of three-state machines **400**, **500**, **600**, or **700**. Methods **2800** and **4200** can be executed on any of three-state machines **400** or **500**. Methods **3100** and **4300** can be executed on any of three-state machines **400** or **500**. Methods **3400** and **4400** can be executed on any of three-state machines **400**, **500**, **600** and **800**. Therefore for three-state machines **400** and **500**, methods **2500**, **2800**, **3100**, **3400**, **4100**, **4200**, **4300** and **4400** can be used singly or in combination. For three-state machine **600**, methods **2500**, **3400**, **4100** and **4400** can be used singly or in combination. For three-state machine **700**, only methods **2500** and **4100** can be used singly or in combination. For three-state machine **800**, only methods **3400** and **4400** can be used singly or in combination.

Other state machines are possible as long as any of three-state machines **400**, **500**, **600**, **700** or **800** remains a corner-stone of the architecture. More states may be added and different transition combinations can be used, any of

which could be realized by those skilled in the art given the disclosure presented herein, and depending upon the particular specifications desired. Moreover concomitant variations in the methods herein described and the form by which conditions are expressed and input to the methods will immediately become apparent to those skilled in the art. For example, iteration over elements of an In-expression could be handled through recursion instead. They can utilize the teachings of this disclosure to create efficient operative embodiments of the system and methods described and claimed. These embodiments are also within the contemplation of the inventor.

I claim:

1. A state machine slave comprising:

three or more states, being at least a first state, a second state, and a third state, the slave being initially in the first state;

a memory with one or more stored information values;

a receiving unit for receiving one or more commands in a command sequence, each of the commands specifying a "transfer from state", "transfer to state", and a primitive condition; and

a processing unit that causes the slave to move to the second state being the "transfer to state" if the first state is the same as the "transfer from state" and one or more of the information values satisfies the primitive condition, the slave being moved to the third state by another command in the command sequence only if the slave is in the second state, and the slave, once moved into the third state, remaining in the third state.

2. A state machine slave, as in claim 1, wherein the first and second states reverse roles after an end of one or more subsequences in the sequence of commands.

3. A state machine slave, as in 2, where the first and second states reverse roles at the end of each subsequence corresponding to a term in a sum of left-nested expressions.

4. A state machine slave, as in claim 3, where the sum of left-nested expressions is a sum of products.

5. A state machine slave, as in claim 1, where the second and third states reverse roles after an end of one or more subsequences in the sequence of commands.

6. A state machine slave, as in claim 5, where the second and third states reverse roles at the end of each subsequence corresponding to a term in a sum of left-nested expressions.

7. A state machine slave, as in claim 6, where the sum of left-nested expressions is a sum of products.

8. A state machine slave, as in claim 1, where states cycle roles as follows: the first state assumes the role of second state, the second state assumes the role of the third state, and the third state assumes the role of the first state after an end of one or more subsequences in the sequence of commands.

9. A state machine slave, as in claim 8, where the first, second, and third states cycle roles at the end of each subsequence corresponding to a term in a sum of left-nested expressions.

10. A state machine slave, as in claim 9, where the sum of left-nested expressions is a sum of products.

11. A system comprising:

two or more slaves, the slaves comprising:

three or more states, being at least a first state, a second state, and a third state, the slave being initially in the first state;

a memory with one or more stored information values;

a receiving unit for receiving one or more commands in a command sequence, each of the commands specifying a "transfer from state", a "transfer to state", and a primitive condition;

a processing unit that causes the slave to move to the second state being the "transfer to state" if the first state is the same as the "transfer from state" and one or more of the information values satisfies the primitive conditions, the slave being moved to the third state by another command in the command sequence only if the slave is in the second state, and the slave, once moved into the third state, remaining in the third state; and

one or more masters for communicating the commands to all the slaves and determining the sequence of commands in order to select a subset of the slaves that satisfy a condition.

12. A system, as in claim 11, where the master is a base station, the slaves are radio frequency tags and the base station communicates with the radio frequency tags with a radio frequency signal.

13. A system, as in claim 11, where the one of the subsequences in the sequence of commands moves one or more first sets of slaves from the first state to the second state, then moves one or more second sets of slaves from the second state to the first state, and then moves the slave remaining in the second state to the third state.

14. A system, as in claim 11, where the one of the subsequences in the sequence of commands moves one or more first sets of slaves from the first state to the second state, then moves one or more second sets of slaves from the second state to the first state, and then moves the slave remaining in the first state to the third state.

15. A system, as in claim 11, where the one of the subsequences in the sequence of commands moves one or more first sets of slaves from the first state to the second state and then moves the slaves in the second state to the third state.

16. A system, as in claim 11, where the one of the subsequences in the sequence of commands moves one or more first set of slaves from the first state to the second state and then moves the slaves in the first state to the third state.

17. A method to generate a sequence of commands that are broadcasted to one or more slaves, the method comprising the steps for:

a. communicating one or more first commands that move zero or more of the slaves from a first state to a second state, the slaves moving from the first state to the second state satisfying a first primitive condition in each respective second command;

b. communicating zero or more second commands that move one or more of the slaves from the second state to the first state, the slaves moving from the first state to the second state satisfying a second primitive condition in each respective second command;

c. repeating steps a and b one or more times;

d. communicating a third command that moves the slaves in the second state into a third state.

18. A state machine slave comprising:

three or more states, being at least a first state, a second state, and a third state, the slave being in the first state;

means for storing one or more stored information values;

means for receiving one or more commands in a command sequence, each command specifying a "transfer from state", a "transfer to state", and a primitive condition; and

means for causing the slave to move to the second state being the "transfer to state" if the first state is the same

as the "transfer from state" and one or more of the information values satisfies the primitive condition, the slave being moved to the third state by another command in the command sequence only if the slave is in the second state, and the slave, once moved into the third state, remaining in the third state.

19. A system comprising:

two or more slaves, the slaves comprising:

three or more states, being at least a first state, a second state, and a third state, the slave being in the first state;

means for storing one or more information values;

means for receiving one or more commands in a command sequence, each command specifying a "transfer from state", a "transfer to state", and primitive condition;

means for causing the slave to move to the second state being the "transfer to state" if the first state is the same as the "transfer from state" and one or more of the information values satisfies the primitive condition, the slave being capable of being moved to the third state by another command in the command sequence only if the slave is in the second state, and the slave, once moved into the third state, remaining in the third state; and

one or more means for communicating each command to all the slaves and determining the sequence of commands in order to select a sub-set of the slaves that satisfy a condition.

* * * * *

CIVIL COVER SHEET

The JS-44 civil cover sheet and the information contained herin neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civl docket sheet. (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM.)

I. (a) PLAINTIFF

INTERMEC IP CORP.

(b) COUNTY OF RESIDENCE OF FIRST LISTED PLAINTIFF _____
(EXCEPT IN U.S. PLAINTIFF CASES)

DEFENDANT

ALIEN TECHNOLOGY CORP.

COUNTY OF RESIDENCE OF FIRST LISTED DEFENDANT _____
(IN U.S. PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED.

(c) ATTORNEYS (FIRM ADDRESS AND TELEPHONE NUMBER)
Jack B. Blumenfeld (#1014)
Rodger D. Smith (#3778)
Morris, Nichols, Arsht & Tunnell LLP
1201 N. Market Street
P.O. Box 1347
Wilmington, DE 19801
302-658-9200

ATTORNEYS (IF KNOWN)

II. BASIS OF JURISDICTION (PLACE AN "X" IN ONE BOX ONLY)

- ☐ 1 U.S. Government Plaintiff
- ☒ 3 Federal Question (U.S. Government Not a Party)
- ☐ 2 U.S. Government Defendant
- ☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES
(For Diversity Cases Only)
(PLACE AN "X" IN ONE BOX FOR PLAINTIFF AND ONE BOX FOR DEFENDANT)

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated or Principal Place of Business in This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated and Principal Place of Business in Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. ORIGIN *(PLACE AN "X" IN ONE BOX ONLY)*

☒ 1 Original Proceeding | ☐ 2 Removed From State Court | ☐ 3 Remanded From Appellate Court | ☐ 4 Reinstated or Reopened | ☐ 5 Transferred From another district (specify) ____ | ☐ 6 Multidistrict Litigation | ☐ 7 Appeal to District Judge from Magistrate Judgement

V. NATURE OF SUIT *(PLACE AN "X" IN ONE BOX ONLY)*

CONTRACT
- ☐ 110 Insurance
- ☐ 120 Marine
- ☐ 130 Miller Act
- ☐ 140 Negotiable Instrument
- ☐ 150 Recovery of Overpayment & Enforcement of Judgement
- ☐ 151 Medicare Act
- ☐ 152 Recovery of Defaulted Student Loans (Excl Veterans)
- ☐ 153 Recovery of Overpayment of Veteran's Benefits
- ☐ 160 Stockholder Suits
- ☐ 190 Other Contract
- ☐ 195 Contract Product Liability

REAL PROPERTY
- ☐ 210 Land Condemnation
- ☐ 220 Foreclosure
- ☐ 230 Rent Lease & Ejectment
- ☐ 240 Torts to Land
- ☐ 245 Tort Product Liability
- ☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
- ☐ 310 Airplane
- ☐ 315 Airplane Product Liability
- ☐ 320 Assault Libel & Slander
- ☐ 330 Federal Employers Liability
- ☐ 340 Marine
- ☐ 345 Marine Product Liability
- ☐ 350 Motor Vehicle
- ☐ 355 Motor Vehicle Product Liability
- ☐ 360 Other Personal Injury

PERSONAL INJURY
- ☐ 362 Personal Injury - Med Malpractice
- ☐ 365 Personal Injury - Product Liability
- ☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- ☐ 370 Other Fraud
- ☐ 371 Truth in Lending
- ☐ 380 Other Personal Property Damage
- ☐ 385 Property Damage Product Liability

CIVIL RIGHTS
- ☐ 441 Voting
- ☐ 442 Employment
- ☐ 443 Housing/ Accommodations
- ☐ 444 Welfare
- ☐ 440 Other Civil Rights

PRISONER PETITIONS
- ☐ 510 Motions to Vacate Sentence

HABEAS CORPUS:
- ☐ 530 General
- ☐ 535 Death Penalty
- ☐ 540 Mandamus & Other
- ☐ 550 Civil Rights
- ☐ 555 Prison Condition

FORFEITURE/PENALTY
- ☐ 610 Agriculture
- ☐ 620 Other Food & Drug
- ☐ 625 Drug Related Seizure of Property 21 USC 881
- ☐ 630 Liquor Laws
- ☐ 640 R R & Truck
- ☐ 650 Airline Regs
- ☐ 660 Occupational Safety/Health
- ☐ 690 Other

LABOR
- ☐ 710 Fair Labor Standards Act
- ☐ 720 Labor/Mgmt. Relations
- ☐ 730 Labor Mgmt. Reporting & Disclosure Act
- ☐ 740 Railway Labor Act
- ☐ 790 Other Lablor Litigation
- ☐ 791 Empl Ret Inc Security Act

BANKRUPTCY
- ☐ 422 Appeal 28 USC 158
- ☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- ☐ 820 Copyrights
- ☒ 830 Patent
- ☐ 840 Trademark

SOCIAL SECURITY
- ☐ 861 HIA (1395ff)
- ☐ 862 Black Lung (923)
- ☐ 863 DIWC/DIWW (405(g))
- ☐ 864 SSID Title XVI
- ☐ 865 RSI (405(g))

FEDERAL TAX SUITS
- ☐ 870 Taxes (U.S. Plaintiff or Defendant
- ☐ 871 IRS - Third Party 26 USC 7609

OTHER STATUTES
- ☐ 400 State Reapportionment
- ☐ 410 Antitrust
- ☐ 430 Banks or Banking
- ☐ 450 Commerce/ICC Rates/etc
- ☐ 460 Deportation
- ☐ 470 Racketeer Influenced and Corrupt Organizations
- ☐ 810 Selective Service
- ☐ 850 Securities/Commodities/ Exchange
- ☐ 875 Customer Challenge 12 USC 3410
- ☐ 891 Agricultural Acts
- ☐ 892 Economic Stabilization Act
- ☐ 893 Environmental Matters
- ☐ 894 Energy Allocation Act
- ☐ 895 Freedom of Information Act
- ☐ 900 Appeal of Fee Determination Under Equal Access to Justice
- ☐ 950 Constitutionality of State Statutes
- ☐ 890 Other Statutory Actions

VI. CAUSE OF ACTION (CITE THE U.S. CIVIL STATUTE UNDER WHICH YOU ARE FILING AND WRITE BRIEF STATEMENT OF CAUSE DO NOT CITE JURISDICTIONAL STATUTES UNLESS DIVERSITY)

Patent infringement under 35 U.S.C. §271

VII. REQUESTED IN COMPLAINT
☐ CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23
DEMAND $
CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ YES ☐ NO

VIII. RELATED CASE(S) IF ANY (See Instructions)
JUDGE Sleet DOCKET NUMBER 04-357-GMS

DATE 6/29/06
SIGNATURE OF ATTORNEY OF RECORD Jack B Blumenfeld

FOR OFFICE USE ONLY

RECEIPT # _____ AMOUNT _____ APPLYING IFP _____ JUDGE _____ MAG. JUDGE _____

AO FORM 85 RECEIPT (REV. 9/04)

United States District Court for the District of Delaware

Civil Action No. 06-411

ACKNOWLEDGMENT OF RECEIPT FOR AO FORM 85

NOTICE OF AVAILABILITY OF A UNITED STATES MAGISTRATE JUDGE TO EXERCISE JURISDICTION

I HEREBY ACKNOWLEDGE RECEIPT OF 1 COPIES OF AO FORM 85.

6/29/06
(Date forms issued)

Philip J. Margiotta
(Signature of Party or their Representative)

Philip J. Margiotta
(Printed name of Party or their Representative)

Note: Completed receipt will be filed in the Civil Action